1978

The use of slags for the prevention of magnesium fade in cast iron melts

Peter Pei-Kuei Shaw
University of Windsor

37166

National Library of Canada

Bibliothèque nationale du Canada

CANADIAN THESES ON MICROFICHE

THÈSES CANADIENNES SUR MICROFICHE

NAME OF AUTHOR/*NOM DE L'AUTEUR* Peter Pei-Kuei Shaw

TITLE OF THESIS/*TITRE DE LA THÈSE* The use of slags for the prevention of magnesium fade in cast iron melts.

UNIVERSITY/*UNIVERSITÉ* University of Windsor, Windsor, Ontario

DEGREE FOR WHICH THESIS WAS PRESENTED/ *GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE* M.A.Sc.

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE DEGRÉ* May 1978

NAME OF SUPERVISOR/*NOM DU DIRECTEUR DE THÈSE* Dr. W. V. Youdelis

Permission is hereby granted to the NATIONAL LIBRARY OF CANADA to microfilm this thesis and to lend or sell copies of the film.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

L'autorisation est, par la présente, accordée à la BIBLIOTHÈQUE NATIONALE DU CANADA de microfilmer cette thèse et de prêter ou de vendre des exemplaires du film.

L'auteur se réserve les autres droits de publication; ni la thèse ni de longs extraits de celle-ci ne doivent être imprimés ou autrement reproduits sans l'autorisation écrite de l'auteur.

DATED/*DATÉ* May 12/78 SIGNED/*SIGNÉ* P. K. Shaw

PERMANENT ADDRESS/*RÉSIDENCE FIXE* 3 Fl. 75 Alley 9 Lane 52 Chung-Shing ST YungHo, Taipei Taiwan

NOTICE

The quality of this microfiche is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us a poor photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this film is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30. Please read the authorization forms which accompany this thesis.

THIS DISSERTATION HAS BEEN MICROFILMED EXACTLY AS RECEIVED

AVIS

La qualité de cette microfiche dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de mauvaise qualité.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, examens publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de ce microfilm est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30. Veuillez prendre connaissance des formules d'autorisation qui accompagnent cette thèse.

LA THÈSE A ÉTÉ MICROFILMÉE TELLE QUE NOUS L'AVONS REÇUE

THE USE OF SLAGS FOR THE PREVENTION OF
MAGNESIUM FADE IN CAST IRON MELTS

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES THROUGH
THE DEPARTMENT OF ENGINEERING MATERIALS IN PARTIAL
FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF APPLIED SCIENCE AT THE
UNIVERSITY OF WINDSOR

by

PETER PEI-KUEI SHAW

WINDSOR, ONTARIO
1978

UNIVERSITY OF WINDSOR

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled

THE USE OF SLAGS FOR THE PREVENTION OF MAGNESIUM FADE IN CAST IRON MELTS

submitted by PETER PEI-KUEI SHAW

in partial fulfilment of the requirements for the degree of Master of Applied Science.

(Supervisor)

D.O. Northwood

Date: May 11, 1978

ABSTRACT

The rate of volatilization loss of magnesium from cast-iron melts covered with slags of various compositions is investigated. It is shown that the rate of magnesium loss is significantly decreased at temperatures up to 1550 C and for times up to 30 minutes when the melts are covered with chloride salt-silicon alloy composite slags. The increased magnesium retention results in a corresponding improvement in the graphite nodularity of the ingot microstructure. The $BaCl_2$-Si slag, approximately 50% of each constituent, gives the best results. It is postulated that the retardation of the rate of magnesium loss is the result of the relative slow diffusion transport of magnesium through the layer.

ACKNOWLEDGEMENTS

This research was carried out in the Department of Engineering Materials at the University of Windsor in Windsor under the direction of Dr. W. V. Youdelis. The assistance of Mr. George Vazsonyi and Mr. John Robinson for photography, X-ray diffraction analysis and image analysis was indispensable. Special thanks are also made to Dr. M. N. Srinivasan who contributed his time and knowledge in my research.

TABLE OF CONTENTS

page

LIST OF FIGURES

Figure page

LIST OF TABLES

I. INTRODUCTION

Cast irons are of three general types; white, gray and nodular. Most of the carbon in white iron is present as cementite (Fe_3C) while in gray iron a large proportion of the carbon is present as graphite in the form of flakes. The carbon in nodular iron is present as graphite spheroids that do not not disrupt the continuity of the ferrite (α-Fe) matrix as do graphite flakes, and so the strength and ductility of nodular iron is relatively high. Thus, nodular iron castings can replace steel casting for many applications since it has a tensile strength comparable to plain (low) carbon steels. Other favorable properties such as high damping capacity and good machinability further advance the applicability of nodular iron. Table 1 gives the values of several engineering properties of cast ferrous alloys for comparison[1].

Nodular iron is also known as ductile iron or spheroidal graphite (S. G.) iron. This material was first discovered by H. Morrogh of The British Cast Iron Research Association in 1948. He presented a paper at the 1948 Annual Meeting of American Foundrymen Society (AFS) entitled "Production of Nodular Graphite Structures in Gray Cast Irons", which described the use of the cerium to obtain the spheroidal graphite structure. Soon after this announcement was made, it was followed by another giving particulars of the magnesium process developed by International Nickel Ltd. In most commercial applications both magnesium and

Alloy class	Tensile strength psi	Elongation %	Yield strength psi	Modulus of elasticity psi
Gray Iron	25,000-60,000	<1	Does not exhibit definite values	14,000,000-20,000,000
White Iron	50,000-60,000	<1	As for gray iron	As for gray iron
Nodular Iron	55,000-120,000	≤18	40,000-90,000	21,000,000-25,000,000
Carbon Steel	64,000-130,000	20-35	35,000-75,000	around 30,000,000
Alloy Steel	70,000-200,000	5-35	45,000-170,000	As for carbon steel

Table 1. Comparison of Cast, Ferrous Alloys (after J. Gerin Sylvia[1])

cerium are employed. However, magnesium is the less costly and more versatile nodularizing agent than cerium.

Since the introduction of nodular iron, a considerable number of advances have been made in foundry practice relating to this material. However, the most troublesome problem still remaining in the production of nodular iron is the loss of magnesium from the melt by volatilization. The decrease of residual magnesium content with elapse of time is called "fading", which results in a corresponding decrease in the degree of "nodularity" of the graphite, i.e. the nodule becomes irregular (wormy) in shape and is referred to as "vermicular" graphite. The graphite nodule ultimately reverts to a flake form when the residual magnesium content of the cast iron falls to 0.01%* or lower.

This investigation was undertaken with the aim of developing a suitable slag that would prevent or retard magnesium fade when applied to the surface of magnesium-inoculated cast iron melts. Several slag composites were studied, and the most effective slag developed is a chloride salt-silicon alloy composite containing about equal amounts of barium and/or calcium chloride and silicon or ferrosilicon alloy. It remains to determine by in-plant studies the effectiveness of the slag and the feasibility of its use in commercial production of nodular iron.

* All concentrations in wt%

II. LITERATURE REVIEW

A. Phase Diagram of Cast Iron

Cast iron is essentially a ternary iron-carbon-silicon alloy, and an accurate representation of the alloy system would require presenting several isothermal and vertical sections of the ternary phase diagram. However, for our purposes it is sufficient and more expedient to show how the binary iron-carbon phase diagram (Fig. 1) is affected by the silicon content present in typical cast irons. This is illustrated in Fig. 2, which is a schematic representation of the vertical section through an iron-carbon-silicon ternary at 3.5% silicon[2]. The principal effect of the silicon is to transform the isothermal eutectic and eutectoid reactions to three-phase fields extending over a temperature range which increases with silicon content. In cast irons the graphite-carbide ratio and distribution is largely determined by the eutectic reaction which varies depending on the temperature at which it occurs. In the upper region of the three-phase field carbon generally precipitates as stable graphite, while in the lower region carbon may precipitate as graphite or metastable iron carbide (Fe_3C) depending on the silicon content and cooling rate through the three-phase region. In general a higher silicon content and lower cooling rate promote the formation of graphite (gray iron), while lower silicon levels and rapid solidification rates promote carbide formation (white iron).

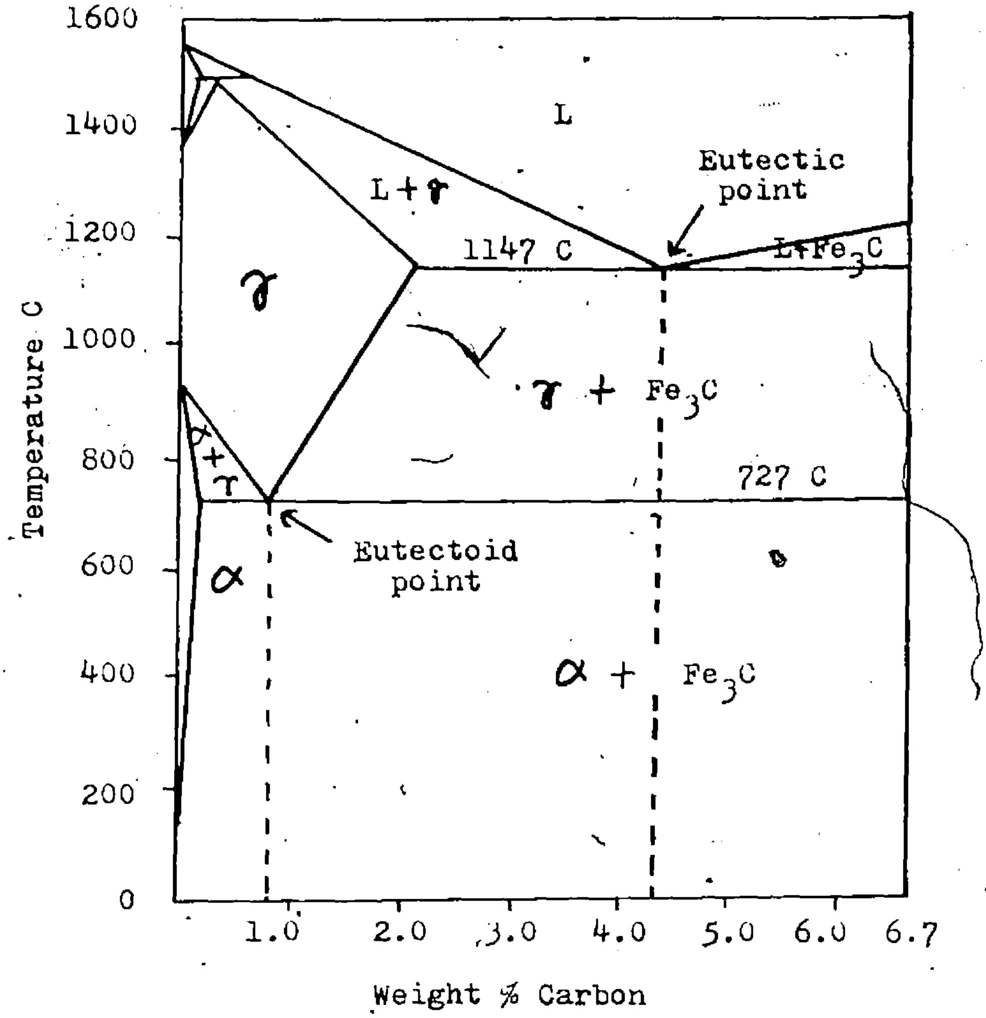


Fig. 1. The iron-carbon phase diagram.
(L: Liquid, γ : Austenite, α : Ferrite)

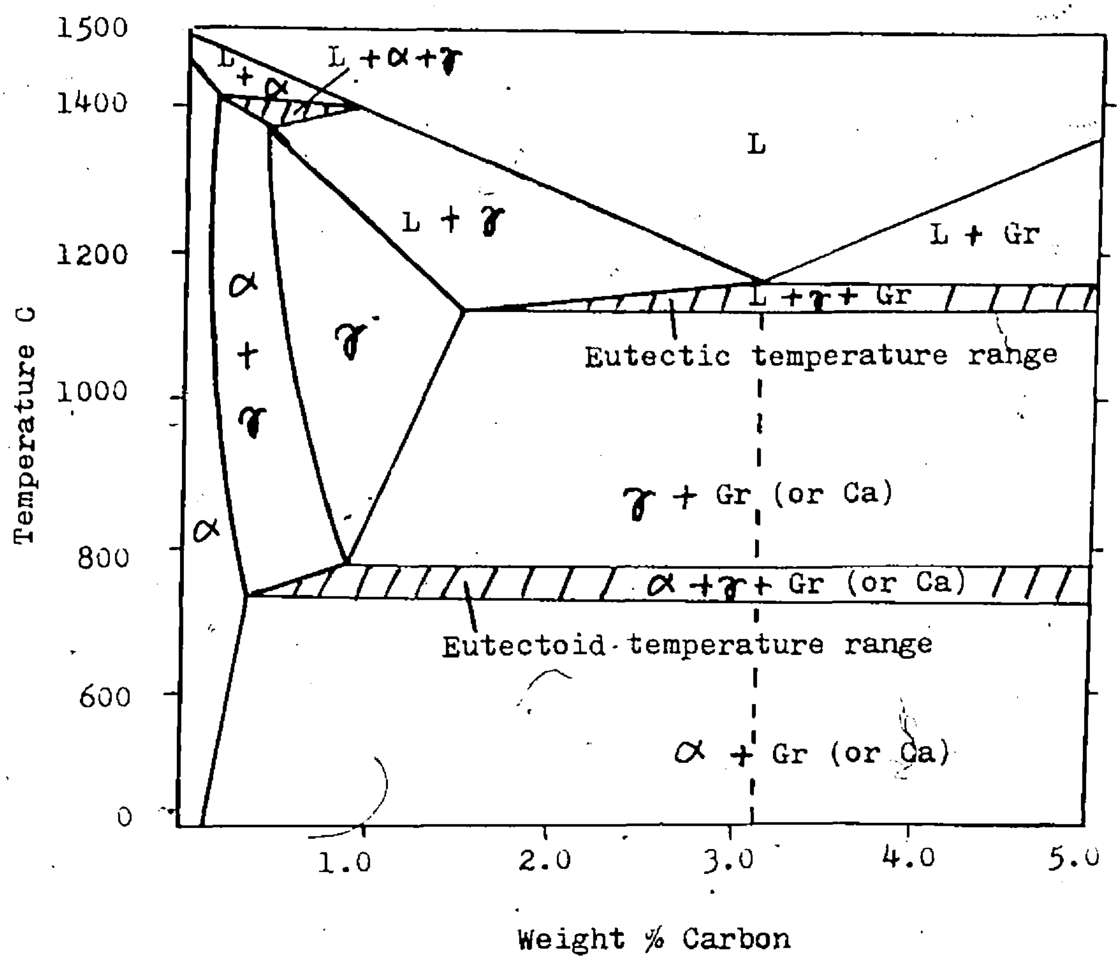


Fig. 2. A vertical section of the Fe-C-Si system at constant 3.5% Si concentration
(L: Liquid, γ: Austenite, α: Ferrite, Gr: Graphite, Ca: Carbide) (after J. E. Hiliard and W. S. Owen[2])

Silicon also significantly decreases the solubility of carbon in iron and shifts the eutectic reaction to lower carbon concentrations. The latter can be expressed by the relation[3]:

$$\text{Eutectic carbon \%} = 4.25\% - 0.3\cdot(\% \text{ Si}) \quad \ldots\ldots \quad \text{(Eq. 1)}$$

where 4.25% is the eutectic composition for the binary iron-carbon system. Thus for an iron-carbon-silicon alloy containing about 3.5% silicon the eutectic occurs at about 3.1% carbon as shown in Fig. 2.

In gray cast iron the eutectic graphite flakes cluster within the eutectic cells. The flakes may be large or small, abundant or sparse, straight or curled. The silicon content of the cast iron and cooling rate play a major role in determining the quantity and morphology of the graphite flakes. In nodular or ductile cast iron the graphite nucleates and grows spheroidally. The graphite nodule count, size, and nodularity (sphericity) depend on cooling rate, silicon content, and the residual magnesium content of the cast iron.

B. Graphite Nodularization (Spherodization)

The spheroidal graphite structure of nodular iron is produced by the addition of one or more graphite-spherodizing agents of which magnesium is the most commonly used. The process is called nodularization and a number of theories have been postulated for its occurrence. The following are brief descriptions of the more commonly proposed theories:

1.) Minimum surface free energy theory[4]:

A melt containing certain surface-active elements has a low graphite-melt interfacial energy and will solidify to produce flake graphite. When certain alkali metals or alkaline earths, e.g. magnesium, are added, the graphite-melt interfacial energy increases, and when a critical interfacial energy value is reached, the growth mode of the graphite changes to produce spheroidal shapes in an attempt to minimize the total free energy of the system.

2.) Surface-active element growth theory[5, 6]:

It is hypothesized that predominant crystal growth normally occurs along the pole of the plane with the lowest interfacial energy in contact with the liquid. When surface-active elements are adsorbed onto certain crystallographic planes (basal or prism) of the graphite lattice, the interfacial energy of these planes are reduced. For example, sulfur is adsorbed predominantly on the prism plane; therefore, in the presence of sulfur the prism plane exhibited the lowest interfacial energy and growth occurred along the prism pole to produce flake graphite. In the presence of magnesium, the basal graphite plane has the lowest interfacial energy and growth occurs along the basal pole to produce the nodular graphite shapes.

3.) Undercooling theory[7]:

This theory postulates that the spheroidal graphite can be produced by undercooling the molten iron as well as by the introduction of magnesium. Bolotov[7] has shown that in pure iron -carbon-silicon melts, the degree of undercooling obtained is least when graphite platelets form. It is proposed that flake graphite in normal industrial cast irons is due to the presence of sulfur and oxygen, these impurities preventing any significant undercooling of the melt by reducing the graphite-melt interfacial tension and also producing (Fe,Mn)S nuclei for the graphite to crystallize on. In modified iron, however, magnesium removes the impurities from the melt as stable insoluble compounds (MgO, MgS) which do not form crystallization centers for graphite. Thus, the melt is purified and the undercooling required for spheroidal graphite formation is produced.

9

C. Nodularizers

Generally, the most widely used nodularizing agent is a ferrosilicon-base alloy containing 5% to 9% magnesium. Nickel-magnesium alloys, which are more costly, are next in order of usage. Pure magnesium is rarely used.

The magnesium containing ferrosilicon (FeSiMg) nodularizer is favored in the industry for two principal reasons. The ferrosilicon is an excellent carrier for the highly reactive magnesium, and the magnesium vapor pressure is lowered to manageable levels when it is present in the ferrosilicon in concentrations below 10%. The calculated magnesium vapor pressure in ferrosilicon alloys is a function of temperature and magnesium concentration as shown in Fig. 3. It is evident that at the usual foundry working temperature ~ 1500 C, the magnesium vapor pressure for a 5.5% magnesium ferrosilicon alloy exceeds one atmosphere. Thus boiling of the ferrosilicon will occur initially and continue until it is sufficiently mixed and diluted throughout the cast iron melt. The vapor pressure of pure magnesium as a function of temperature is given in Fig. 4, which shows a pressure in excess of 13 atmospheres at 1500 C. This accounts for the vigorous action of pure magnesium, or high magnesium content ferrosilicons, when added to liquid cast iron melts. The released magnesium vapors burn when coming in contact with the atmosphere, giving the pyrotechnics familiar to foundry operators.

D. Magnesium Fade

Magnesium fade is the term applied to the volatilization loss of magnesium from the melt and the consequent deterioration of the graphite nodule shape from a spheroidal to vermicular or ultimately flake form. A typical magnesium fade curve is given in Fig. 5, which shows an exponential decay behaviour with time. In most foundry operations magnesium recovery in the spherodizing

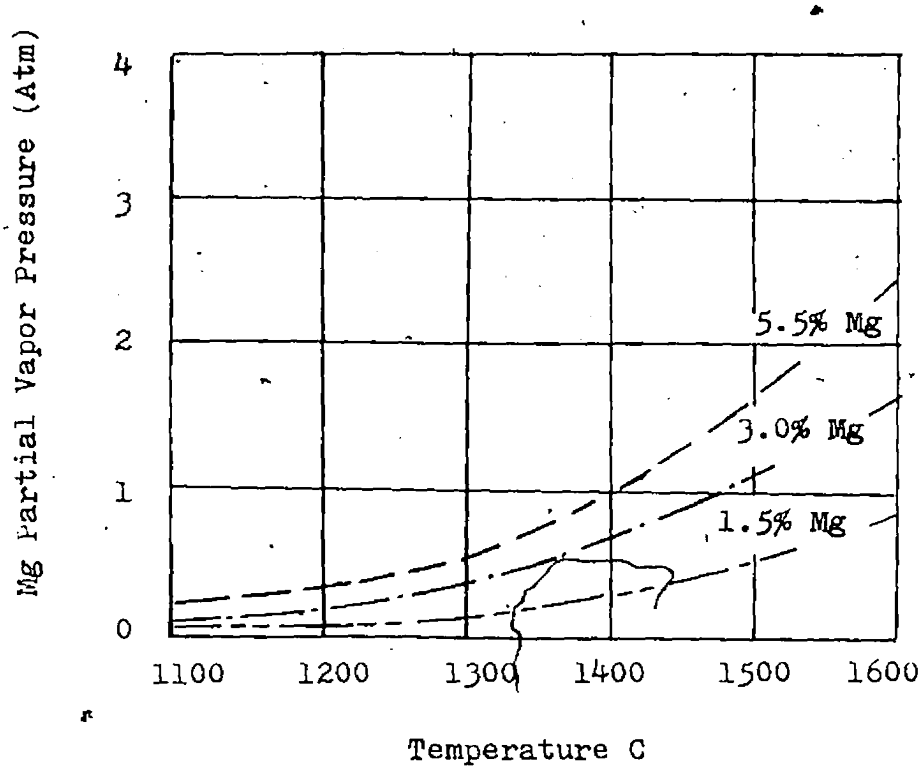


Fig. 3. Calculated Vapor Pressure of FeSiMg Alloy at Cast Iron Melting Temperature (after M. Robinson[8])

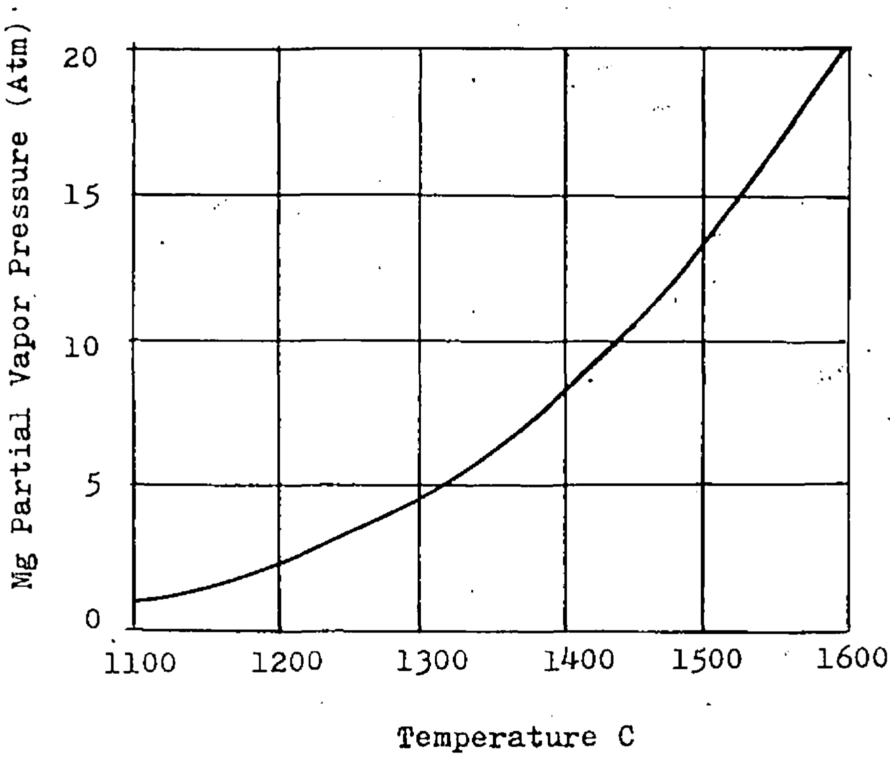


Fig. 4. Vapor Pressure of Pure Magnesium at Cast Iron Melting Temperature (after Trojan and Flinn[9])

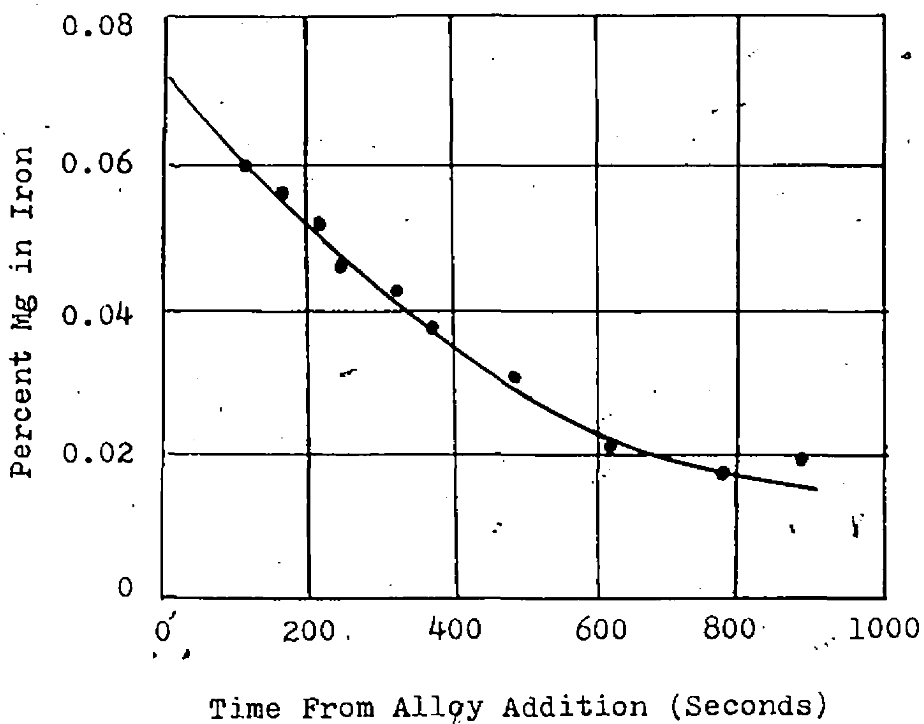


Fig. 5. A Typical Magnesium Fade Curve (after M. Robinson[8])

treatment ranges between 20 and 60 per cent[10]. The amount of magnesium in nodular iron is important. If the level is too low ($<$ 0.01-0.02%), poor nodularity of the graphite results, and if the magnesium concentration is too high ($>$ 0.12%), carbide formation is promoted. A residual magnesium content of about 0.03-0.05% is generally accepted as the best compromise, subject to the kinds and levels of impurities present in the melt[11].

It is evident from Fig. 5 that for initial magnesium additions of about 0.08% (usual foundry practice) the holding time of the melt prior to casting should not exceed 15 minutes if the minimum residual level of about 0.02% magnesium is to be obtained. In general, holding times in foundries are kept as short as possible, and rarely exceed 5 - 7 minutes.

E. Foundry Practice to Overcome the Magnesium Fade Problem

Since the introduction of magnesium as a spherodizing agent much effort has been expended on devising an efficient and safe method of adding it to the melt. The more commonly used methods in foundry practice are as follows:

1.) Open Ladle Method[12, 13]:

The open ladle method is the simplest, but gives the lowest magnesium recovery. In this method, magnesium is added to melt by pouring or tapping base iron over a magnesium alloy that has been charged into the bottom of an open receiving ladle. Usually all of the magnesium alloy is charged at one time, and the cast iron melt is poured or tapped over the magnesium alloy as rapidly as possible. Due to the significantly lower density of the ferrosilicon alloy containing the magnesium, there is considerable flotation and exposure of the nodularizer to the atmosphere, resulting in substantial oxidation losses.

2.) Plunging Method[12, 13]:

In this method magnesium-containing alloy is placed in a refractory bell and forced below the melt in a previously filled ladle. This method yields better magnesium recovery than the open ladle practice because there is very little or no exposure of the nodularizer to the atmosphere at the working temperature. For proper plunger design, alloy density and vapor pressures generated must be considered, and since density and magnesium content of nodularizer alloys vary widely, the plunger capacity is dependent on the type of nodularizer alloy selected.

3.) Sandwich Method[14, 15]:

This method employs a ladle with a base lining of sufficient thickness to allow the formation of a recess or pocket as shown in Fig. 6. Into this pocket the requisite quantity of magnesium-bearing alloy is placed and covered with steel punchings. In this way the reaction is confined to the bottom of the ladle where it occurs at a reduced rate and temperature. The molten iron entering the ladle is directed to the side

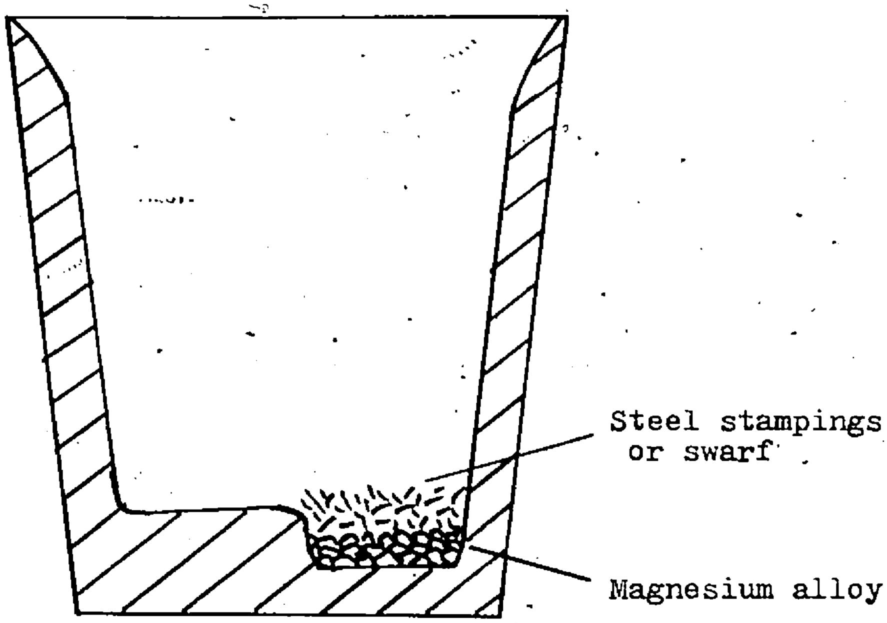


Fig. 6. Ladle for Sandwich Method

away from the depression containing the alloy.

4.) Inmold Method[16]:

In this method the dissolution rate of nodularizer in the iron flow is the governing factor. To solve the problem of uniform dissolution, magnesium-containing ferrosilicon alloy in the form of granules is placed in a chamber suitably shaped to maintain the dissolution rate approximately constant during pouring. Good chamber design should meet the following requirements: i) The chamber should permit a regular iron flow over the alloy to facilitate its gradual dissolution. ii) Chamber design should be such that the undissolved alloy residues dragged by the iron and reaching the cavity are kept to a minimum. Furthermore, it is preferable to widen the section of the entrance and to locate the exit at a level higher than that of the entrance. The exit section must be at least 10% smaller than that of the entrance. When possible, attempts are also made to locate the outlet not in line with the inlet in order to force the liquid into desired circulation on the alloy before reaching the exit.

F. Inoculation

Following the spherodizing or nodularizing treatment the cast iron melt is usually subjected to a treatment known as "inoculation", which is the addition of (usually) a ferrosilicon alloy containing small amounts of aluminum and calcium. Some inoculant alloys also contain magnesium, and in some foundries the spherodizing and inoculation procedures are combined into one single "inoculation" procedure.

The most important effect of inoculation is the graphite nucleating effect in both gray and nodular iron. In gray iron, inoculation treatment increases the number of nuclei in the molten iron and, therefore, creates a larger number of eutectic cells with their clusters of graphite flakes as explained earlier. In any given volume of cast iron, the larger the number of eutectic cells, the smaller is their size, and thus the inoculation treatment is also a means of controlling grain size and density of structure. These changes are accompanied by an increase in mechanical properties coupled with improved machinability. In nodular iron, inoculation treatment increases the graphite nodule count and, therefore, decreases the nodule size. For both gray and nodular irons, the graphite nucleating effect of the inoculation procedure eliminates or decreases the amount of carbide formed.

G. Inoculation Mechanism and Inoculant Alloys

The inoculation mechanism has not been clearly established, particularly as it appears to be specific to the inoculant alloy used. The commonly used inoculants in foundry industry are ferrosilicon, aluminum, calcium silicide, graphite, zirconium, and combinations of all of these. Silicon-based inoculants have received considerably more use than others. It has been reported that inoculants based on silicon are effective only when they contain small amounts of elements such as calcium[17], aluminum[18], cerium[19], barium[20, 21] or strontium[22]. Cole[11] has suggested that calcium and aluminum can produce tiny atom complexes within the melt, perhaps in a carbide form (CaC, AlC), upon which graphite can readily nucleate and grow. He showed that additions of 99.9% pure Fe, Si or FeSi have no effect on increasing the number of growth centers. However Moore[23] has shown that pure silicon is a potent inoculant for both flake graphite and nodular graphite irons when added to the casting sprue, although, little inoculation is produced when it is added to metal in the ladle. It is evident from the above that inoculation procedure in foundries is based more on the art than science of the practice, and optimization of the process needs understanding of the mechanism by which graphite nucleation results. For the present, inoculants are selected through considerable trial and error, and those most effective exhibit the following characteristics:

1.) Slow fading rate, thus giving constant results when a standard addition is used.
2.) Enter the molten iron readily with no adverse effects from an overaddition.
3.) Produce maximum inoculation and chill reduction (minimum carbide formation) from minimum addition.
4.) Leave little residue which is easily removed.
5.) Reduce section sensitivity (chill formation) to a minimum.

The last point above has reference to the extreme change in properties and structure which results between thin and thick sections in uninoculated gray cast iron. Very thin sections may become chilled (brittle and unmachinable) while the thicker sections may be of soft and of very low strength. A properly inoculated gray cast iron will not show these extremes.

H. Inoculant Fade

Analogous to the magnesium fade a definite inoculation fade has been reported by Htun[24]. During and immediately after inoculation, the melt is in a super-inoculated state. Fading of the inoculation effect begins immediately, reducing the remaining inoculation effectiveness by approximately 50% every 5 minutes. After 30 minutes the structure of inoculated gray cast iron look similar to that of uninoculated heats, which is characterized by high carbide/graphite ratios. Htun also showed inoculation fade occurs in nodular graphite iron (see Fig. 7). The treated melt, containing 3.5% C and 2.8% Si, was held at 1493 - 1538 C in a magnesia crucible. The nodule count (which is a measure of the inoculation efficiency) is decreased with the increased holding time after inoculation. In this case, of course, the decreased nodule count might be also caused by the loss of magnesium during holding at such a high temperature (1493 - 1538 C), although the magnesium loss is generally associated with the loss in nodularity.

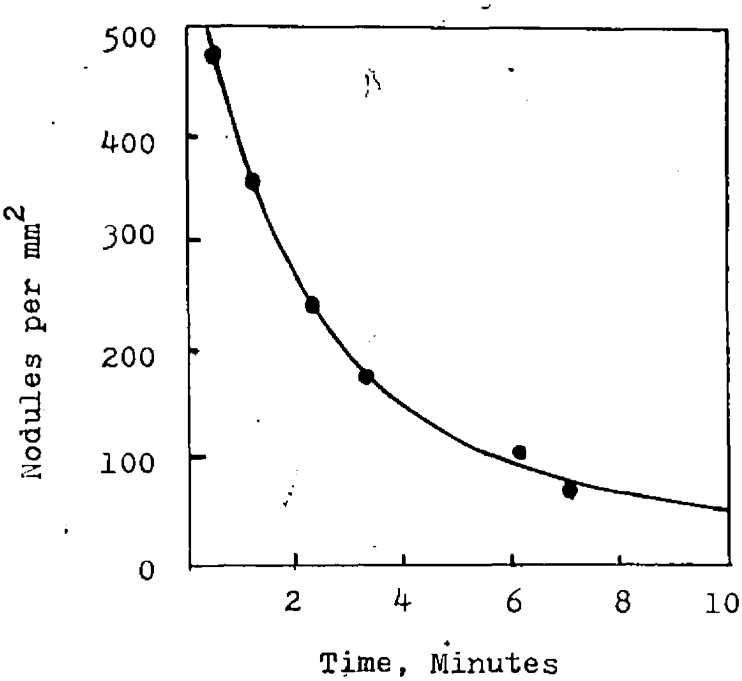


Fig. 7. Effect of Holding Time on Nodule Count in a 3.5% Carbon, 2.8% Silicon Nodular Iron (after Htun[24])

Moore[23] reported that fading of the effect of ferrosilicon inoculation in nodular graphite iron can be markedly reduced by the presence of cerium, either in the iron or dissolved in the inoculant. However, this effect is not consistent, for reasons not yet determined.

I. Foundry Practice to Overcome the Inoculant Fade Problem

In order to counteract inoculation fade, several methods based on late inoculation have been developed, of which the following are the most widely used:

1.) Instantaneous Ladle Inoculation Method[25]:

In this method, crushed ferrosilicon which is bonded with an aqueous solution of Na_2SiO_3 is cast into rod shapes. The lower end of the solid inoculating rod rests on the pouring lip of the ladle and dissolves in the stream of liquid iron throughout the pouring cycle (see Fig. 8). The dissolution rate of the inoculating rods is dependent on pouring temperature and iron flow rate.

2.) Inmold or Instant Inoculation Method[26, 27, 28]:

In this method, the inoculant is added to melt by pouring liquid iron over granular ferrosilicon alloy that has been charged into the bottom of a chamber. Analogous to the Mg-treatment inside the mold, this method eliminates fading, but it needs sufficiently large alloy chamber and suitable chosen alloys to avoid the incorporation of inoculant alloy inclusions into the casting.

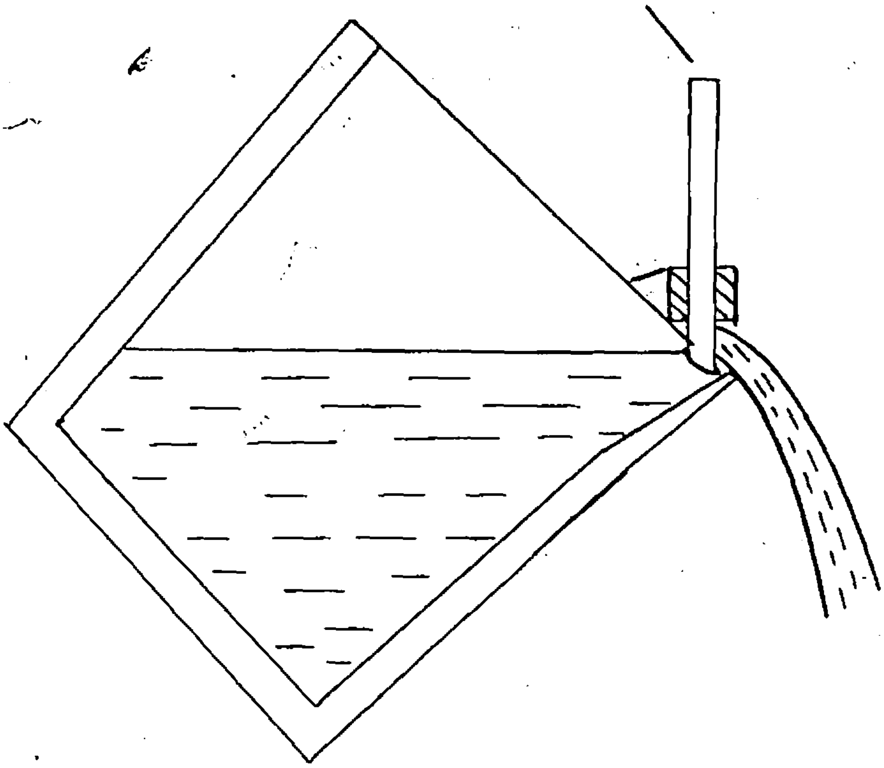


Fig. 8. Instantaneous Ladle Inoculation Principle (after Karsay and Ridley[25])

J. Variables Affecting Nodular Iron Solidification

Nodular iron is a multicomponent alloy system, and therefore highly complex. According to Loper[29] and Cole[11], the major processing variables affecting both the distribution of graphite and matrix properties of nodular iron are:

1.) base iron analysis

2.) residuals present

3.) temperature of nodularization and inoculation

4.) pouring temperature and solidification mode

5.) cooling rate (section size)

Base iron analysis usually refers to the percentage of carbon, silicon, manganese, phosphorus and sulfur. A low sulfur content of 0.025% is desirable since sulfur reacts strongly with magnesium to form magnesium sulfide (MgS), thus diminishing the amount of free magnesium for the nodularization process. It is estimated that about 0.0075% magnesium is subtracted from the melt for each 0.01% sulfur present[30].

The effect of the main alloying elements carbon and silicon, and the impurity element phosphorus on the amount of graphite formed at slow cooling rates, such as in sand molds, can be expressed in terms of an empirical carbon equivalent (C.E.%) relation[31] i.e.

$$C.E. = C\% + (Si\% + P\%)/3 \quad \ldots\ldots\ldots\ldots\ldots \quad \text{(Eq. 2)}$$

which shows that silicon and phosphorus have about one third the graphitizing power of carbon. Equation (2) may be used, in effect, to determine whether a given analysis is hypo- or hyper-eutectic, with the eutectic at about 4.25% carbon for the pure Fe-C binary system. The primary phase crystallizing, i.e. austenite crystals or graphite flakes, and therefore the microstructure and graphite morphology, is dependent on the carbon equivalent.

The C.E. has an effect on the total nodule count in nodular iron, and irons having relatively low C.E. values develop an inadequate number of graphite spheroids. Foundry experience in the production of nodular iron has demonstrated that it is easier to form spheroidal graphite at higher C.E. values, e.g., there are almost twice as many nodules for a C.E. of 4.4 compared to a C.E. of 4.2 for a 2 in. diameter bar[11]. Shaw and Watmough[32] have shown that with a fixed C.E. of about 4.4 higher nodule counts were obtained at a higher silicon content and lower carbon content regardless of section size.

If the C.E. is too high, however, the nodules may become so large that they will float, giving rise to significant graphite segregation (kish graphite) to the top of an ingot or casting. In addition, since nodules are larger at the higher C.E. levels they tend to become unstable leading to chunk and vermicular forms. Therefore, C.E. levels should be maintained at a level low enough to prevent kish graphite forming but high enough to produce a sufficient nodule number that carbide-formation is prevented for all section sizes. Loper[33] stated that for sections greater than 7.6 cm thickness the C.E. should be controlled at a level of 4.3% to 4.35%, while sections between 0.65 cm to 7.6 cm thickness, a C.E. of 4.35% to 4.70% may be used. Usually, in order to achieve this C.E. range, the carbon content of the base iron is best held below 3.90%.

Some studies[34, 35] have shown that residuals such as lead, bismuth, antimony, aluminium, titanium, selenium, and tellurium, in very small amounts, have an inhibiting effect on the formation of the spheroidal graphite structure, although not all investigations on the effect of residual elements are in agreement. Arsenic and tin have a powerful influence in causing the formation of pearlite in irons which would otherwise contain substantial amount of ferrite. Therefore, whether arsenic or tin should be considered as subversive elements depends on the type of nodular iron required. If the aim is to produce a high strength iron with a pearlitic matrix these elements may be ignored, but if the aim is to produce a relatively soft iron of good ductility, then the amounts of tin and arsenic must be kept to a minimum. The influence of copper is complex and depends upon whether the iron contains subversive elements such as titanium, in which case even as little as 1% copper can cause the formation of substantial amount of flake graphite in otherwise nodular iron.

In addition it has been found that a very small amount of cerium is capable of neutralizing these subversive elements. This use of cerium enables pig irons to be used regardless of their subversive element content. Donoho[34] and Morrogh[35] (cf. Table 2) give the maximum levels and harmful levels and levels which can be neutralized by addition of about 0.02% cerium. It must be clearly stated that response to any neutralization by cerium depends not only on quality of the liquid iron used, but also on the conditions of casting. It is well known that a nodularizing or inoculating agent that works very effectively in one foundry does not perform at all in another foundry.

Previous studies[11, 36] have demonstrated that magnesium treatment and inoculation should be accomplished in the temperature range from about 1482 C to 1510 C. If the spherodizing and inoculant alloys are added at a too high a temperature, the effectiveness of nucleating substrates is diminished, which (it is postulated) is a result of the adsorption of oxygen, nitrogen or other impurities, rending them inactive. If added at too low a temperature, the inoculant may not completely dissolve and react with the melt components to form the complex which forms the substrate for nucleation.

The holding time for a Mg-treated melt after inoculating is critical, especially in small heats (less than 200 lbs) where reactions with the atmosphere occur readily. In addition to the fade problem, the holding time for an inoculated melt also affects the graphite structure. Maximum inoculation effect occurs immediately

Inhibiting elements	Max. level %	Harmful level %	Level for neutralization with 0.02% Ce
Lead	0.002	0.01	0.014
Bismuth	0.002	0.005	0.006
Antimony	0.002	0.01	0.015
Aluminium	0.05	0.15	0.50
Titanium	0.05	0.08	0.15
Selenium	0.03	0.05	-
Tellurium	0.03	0.05	-
Tin	0.05	-	-
Arsenic	0.1	-	-
Copper*	1.0-2.0	-	-

(*: depends on the amount of other trace elements such as titanium,... etc.)

Table 2. Maximum Levels of Inhibiting Elements in Nodular Iron (after Donoho[34] and Morrogh[35])

after the addition is made and becomes less with the passage of time. Therefore, the treatment should be applied to the molten iron at as late a stage as possible prior to casting. Generally, casting temperatures near 1480 C are a best compromise between the higher temperatures which reduce magnesium recoveries and the lower temperatures which yield more carbide and poorly formed spheroids.

It is well-known that rapid cooling and solidification significantly increase nodule count, although there is a limit because of chill carbide formation. Askeland and Gupta[37] have derived the following approximate relationship between the solidification rate and the nodule count:

$$\text{nodule count} = A\,\Delta t^{-m}. \quad \ldots\ldots\ldots\ldots\ldots \quad \text{(Eq. 3)}$$

where Δt is the solidification time (seconds) through the eutectic, and A and m are constants. Generally, casting with no mold inoculation A and m are 712 and 0.3675 respectively, and for effective inoculation (e.g. with the mold insert), the A and m values are corresponding increased to 2035 and 0.4190 respectively.

K. Image Analysis of Nodular Graphite

To overcome the problems in visual nodularity determination, a quantitative metallographic analysis (image analysis) has been investigated by Capeletti and Hornaday[38] as a means of obtaining a more objective evaluation of graphite shape morphology and distribution. They showed that significant variations in graphite shape within the same 10 mm square cross-section of a sample required analysis of 15 different areas to assure, within a 95% confidence level, that the true mean shape factor had been determined. Shape Factor (S.F.) of a single graphite particle is defined by Capeletti and Hornaday as

$$\text{S.F.} = \frac{\text{Actual Area of Graphite Particle}}{\text{Area of Imaginary Circle Circumscribing Particle}} \quad \text{.. (Eq. 4)}$$

The shape factor, which has a range of zero to one, is independent of particle size and orientation. A shape factor approaching zero would be applicable to a graphite flake, while a shape factor of one denotes a perfectly spherical nodule.

Determination of average shape factor for the numerous graphite particles present in a nodular iron sample requires use of an image analyzer, such as a quantitative television metallograph, which can rapidly scan a sample. The area of the imaginary circumscribed circle must be calculated from either of two geometric parameters; maximum horizontal chord length or vertical intercept length, which can be used as estimates of the diameter of the imaginary circle. Operating experience has indicated that the larger of these two parameters produces the least error.

III. EXPERIMENTAL METHODS

A. Preparation of Crucibles and Molds and Temperature Measurement

All the experimental heats were made using a high frequency induction furnace (Philips, 500 KH, 12 KVA). Approximately 100 gm charges of base metal were melted in a graphite crucible. The dimensions of the graphite crucible are shown in Fig. 9. The large hole on the right side is the crucible cavity designed for charging the metal, nodularizer, and the inoculant, and the small hole on the left side is the thermocouple well designed to take a Pt/Pt-10%Rh thermocouple, whi thermocoupleed with a alumina sheath. The temperature was measured using a digital temperature indicator (Doric 400 Trendicator). The crucible could easily be maintained to ± 5 C and generally to ± 1 C of the desired temperature (1350-1550 C) for up to 30 minutes or longer. Glass or Pyrex tubes, approximately 16 mm in diameter were used for the molds. The tubes were imbedded in sand (contained in a steel can) to provide structural stability for the molds and a means to control the cooling rate. For fast cooling rates the melt was poured into the tube molds imbedded in room temperature sand, and for slow cooling rates the sand-imbedded glass tube mold and receptacle was first preheated to 450 C. Figures 10a and 10b are photographs shown pouring of the metal and the resulting ingot (after removal from the glass tube mold). A typical cooling curve

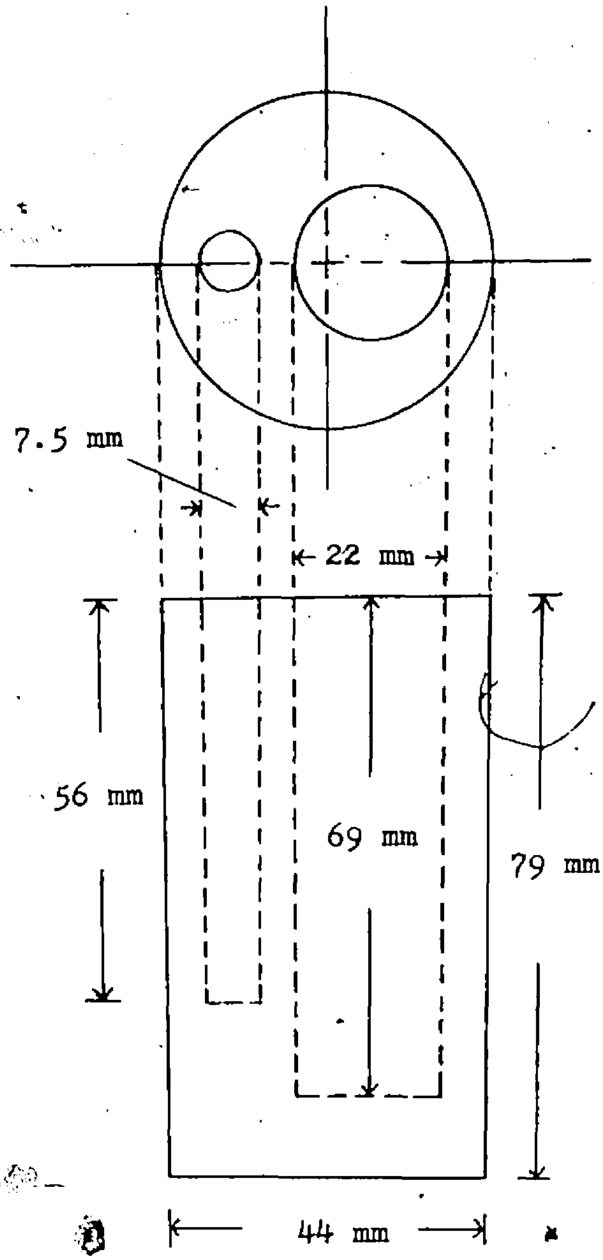
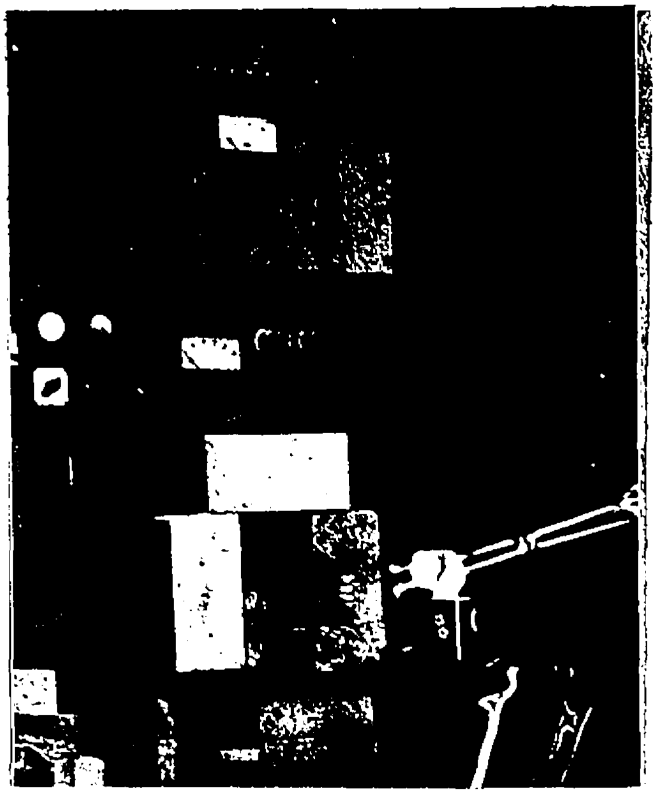


Fig. 9. The Dimensions of The Graphite Crucible



(a)

(b)

Fig. 10. (a) Pouring of the metal, and (b) the resulting ingot after removal from the glass tube mold

obtained by a strip chart recorder (Hewlett Packard, 100 μv Input Module-17505A) is shown in Fig. 11. The cooling rate for the fast and slow solidified ingots measured (slope of the cooling curve at point A, see Appendix 1) approximately 40 C/sec and 20 C/sec respectively.

B. Charging and Stirring Procedures

The incorporation of the FeSiMg into the melt proved to be a very formidable problem. When the FeSiMg was added to the melt without any protective cover, excessive turbulence and pyrotechnics resulted due to the rapid effusion of magnesium vapor and its oxidation on contact with air. It was found that little or no magnesium was incorporated into the melt except when measures were taken to eliminate or minimize the pyrotechnic action of the FeSiMg. The procedure used was as follows: 4 gms of nodularizer (FeSiMg) was placed in the bottom of the crucible and covered with 4 gms barium chloride ($BaCl_2$) or calcium chloride ($CaCl_2$). The magnesium content of the nodularizer alloy was approximately 5%, so that incorporation of all of the magnesium into the melt would give an initial magnesium level of 0.2%. Approximately 100 gms of cast iron was then placed on the surface of the salt-covered nodularizer and the crucible then heated until the cast iron melted (1250 C-1300 C). By this procedure the salt liquifies well in advance of the nodularizer, since the melting points of $BaCl_2$ and $CaCl_2$ are 963 C and 762 C

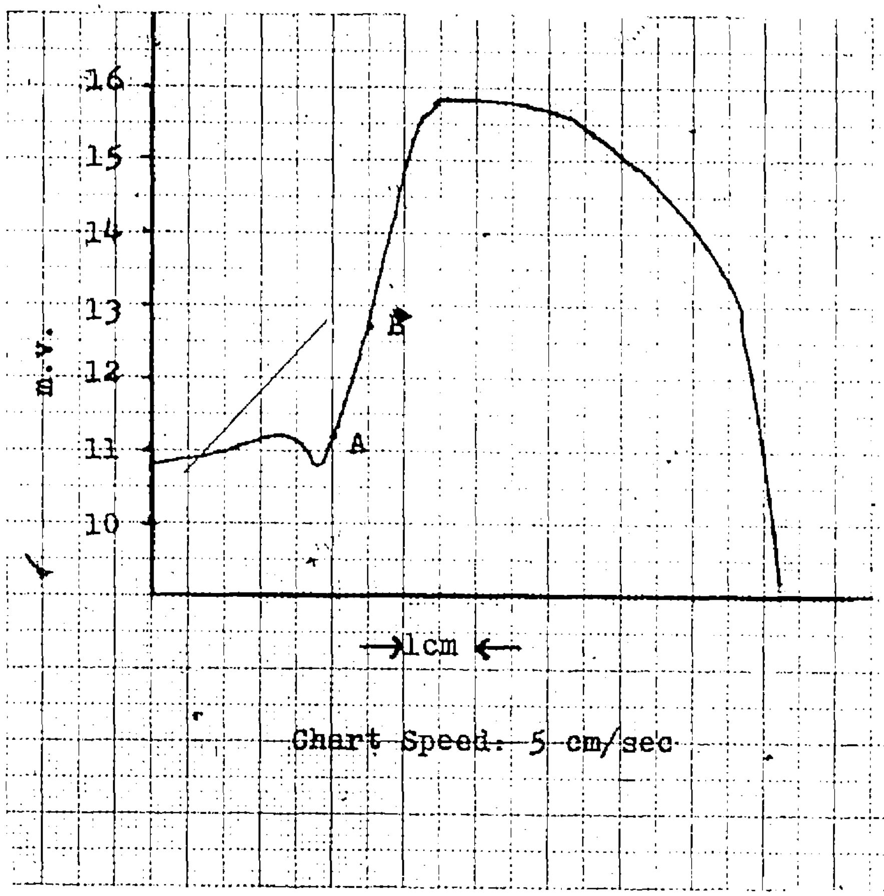


Fig. 11. A Typical Cooling Curve
(Slow Cooling Rate)

respectively, compared to about 1180 C for the FeSiMg alloy. The liquid chloride salt provides a protective surface cover over the denser FeSiMg, preventing any contact of the FeSiMg with air. The subsequent melting of the denser cast iron results in its sinking and mixing with the molten FeSiMg, all the while displacing the molten salt to the surface due to its substantially lower density, thus continually providing the bath protection against the atmosphere. The molten alloy was then briefly stirred with a thin graphite rod to ensure that all of the magnesium was incorporated into the melt. Following stirring, the requisite amount (2 to 4 gms) of slag powder, comprised of a chloride salt-silicon alloy composite, was charged onto the surface of the melt, which on melting spreaded uniformly across the melt surface to provide the molten slag layer for magnesium fade protection. The magnesium inoculated and slag covered melt was then raised to the desired temperature by adjusting the power input, held at temperature for the required time, and then poured. The above alloy preparation technique resulted in the incorporation of about 40 to 60% of the magnesium charged into the melt, giving an initial residual magnesium level in the ingots of about 0.08 to 0.12%. Each ingot was examined metallographically and then chemically analyzed for residual magnesium (Detroit Testing Laboratory Inc.).

IV. RESULTS AND DISCUSSION

A. Composition of Base Irons, Inoculant, Nodularizer and Slags

The three base irons used in this investigation are designated as: (a) Ford material, (b) Bendix material, and (c) Hanna material. The Ford material (crankshaft sprues) was used for most of the tests, and the other materials were used in only a few tests to determine the effect of composition on the rate of magnesium fade. The Bendix material is high in sulfur and was generally difficult to nodularize, indicating that much of the free magnesium was lost to the melt due to its reaction with sulfur. The compositions of the materials, determined spectrographically by Detroit Testing Laboratory Inc., are given in Table 3. Table 4 and 5 give the compositions of nodularizer, inoculant, and the slags used. The slags are chloride salt-silicon alloy powder composites. Some of the slag composites were first fused at 1500-1550 C and then powdered, while others were prepared by mixing requsite amounts of powders of the chloride salt and silicon alloys. The fused slags were examined by X-ray diffraction to determine if any reactions occur between the chloride salt and silicon alloy at melt temperatures.

B. X-ray Diffraction Analyses of Slags

X-ray diffraction analyses, using CuK_{α} radiation, were

Element	Ford material	Bendix material	Hanna material
Carbon	3.464	3.376	3.592
Phosphorus	0.018	0.088	0.024
Sulfur	0.012	0.124	0.012
Manganese	0.55	0.69	0.62
Silicon	3.1	2.9	3.0
Magnesium	0.025	$<$ 0.001	0.008
Chromium	0.10	0.02	0.11
Molybdenum	$<$0.05	$<$0.05	$<$0.05
Nickel	0.08	0.02	0.05
Vanadium	$<$0.01	0.01	$<$0.01
Copper	0.16	0.13	0.23
Titanium	0.03	0.04	0.03
Aluminum	0.01	$<$0.01	0.01

Table 3. Composition of Base Irons (wt%)

Element	Inoculant	Nodularizer (FeSiMg)
Si%	73-78	44-48
Mg%	-	4.75-6.25
Ca%	0.5-1.5	-
Al%	-	-
Ce%	-	0.30
Fe%	Balance	Balance

Table 4. Composition of Inoculant and Nodularizer

Slag No.	$BaCl_2$ %	$CaCl_2$ %	Si powder %	Fe powder %	FeSi* %	Nodularizer (FeSiMg) %	Inocu. %	Comment
I	-	50	-	-	-	50	-	fused (1500-1520 C)
I-1	-	50	-	-	-	50	-	fused (1200-1250 C)
I-2	-	50	-	-	-	50	-	-
I-3	-	66.7	-	-	-	33.3	-	fused (1500-1520 C)
II	50	-	-	-	-	50	-	-
II-2	50	-	-	-	-	50	-	-
II-3	50	-	-	-	-	37.5	12.5	-
II-4	90	-	-	-	-	8	2	-
II-5	20	-	-	-	-	64	16	-
II-6	95	-	-	-	-	4	1	-
II-7	50	-	-	-	-	-	50	-
II-8	50	-	-	-	50	-	-	-
II-9	50	-	-	40	10	-	-	-
II-10	50	-	50	-	-	-	-	-

Table 5. Composition of Slags (wt%)

Slag No.	$BaCl_2$ %	$CaCl_2$ %	$MgCl_2$ %	Si powder %	Nodularizer (FeSiMg) %	Inocu. %	Comment
II-13	90	-	-	10	-	-	-
II-14	95	-	-	5	-	-	-
II-15	95	-	-	-	-	5	-
II-16	50	-	-	50	-	-	fused (1500-1530 C)
Ex-II	23	-	-	-	77	-	fused (1500-1520 C)
III	-	43	-	-	43	14	-
III-1	-	43	-	-	43	14	-
IV	-	39	4	-	43	14	fused (1500-1520 C)
V	39	-	4	-	43	14	-

Table 5. Cont'd

Slag No.	$BaCl_2$ %	$CaCl_2$ %	$CaSi_2$* %	Calsibar* %	SiC %	Comment
II-17	50	-	50	-	-	fused (1500-1530 C)
II-18	50	-	-	50	-	"
II-19	-	50	50	-	-	"
II-20	50	-	-	-	50	"

*	FeSi*	CaSi*	Calsibar*
Fe%	50	3.0 Max.	4.05 Max.
Si%	50	62-67	57-62
Ca%	-	28-32	14-17
Ba%	-	-	14-18

Table 5. Cont'd

performed on slags II, II-3, II-13 and II-16 to determine if any reactions occurred between the $BaCl_2$ and the silicon alloy constituent at melt temperatures. Slags II (50% $BaCl_2$-50% FeSiMg) and II-16 (50% $BaCl_2$-50% Si), which were first fused at 1500-1520 C and then powdered, contain the same components as non-fused slags II-3 (50% $BaCl_2$-37.5% FeSiMg- 12.5% $FeSi_2$) and II-13 (90% $BaCl_2$-10% Si) respectively. Thus, if any compounds formed during fusing, these should become evident on comparing the diffraction patterns. The diffraction results are given in Appendix 2. The diffraction trace for pure silicon powder is also given for the convenience of identifying the silicon peaks in slags II-13 and II-16.

In general, the diffraction patterns for the fused and non-fused slags were essentially similar, indicating that there was little, if any, reaction of the chloride salt with the silicon alloy constituent. The only significant change that occurred, both in the fused and non-fused slags, was the hydration of the chloride salts. Several peaks appeared which could be related to different forms of hydrated $BaCl_2$ ($BaCl_2 \cdot H_2O$, $BaCl_2 \cdot 2H_2O$), and whose intensities increased with time as might be expected.

C. Image Analyses: Determination of Nodularity, Nodule Count and Nodularization Index

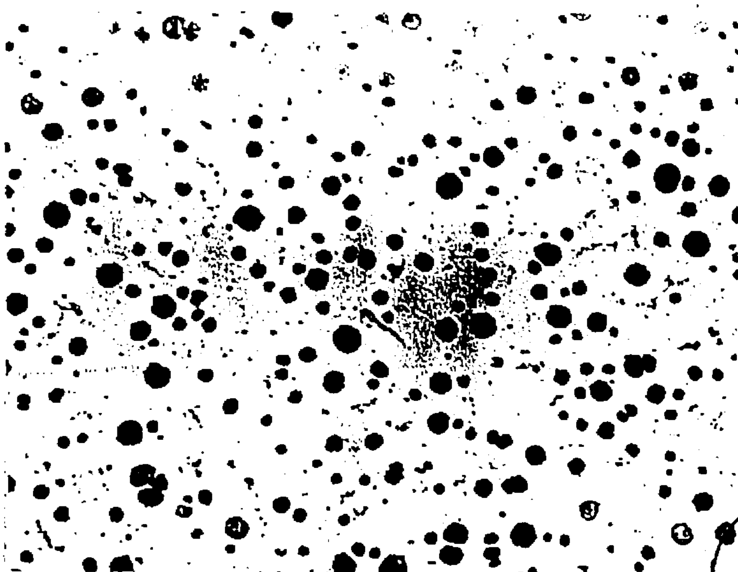
The image analysis computer printout data are tabulated in Appendix 3. Specimens were analyzed in the polished and unetched condition for particle number, particle size distribution and particle min/max diameter distribution. The above parameters were averaged from 5 different areas of each sample, giving a total analyzed area of 2.45 mm^2 per ingot. The results for all the ingots cast are summarized in tabular form in Appendix 4.

The computer printout data of Appendix 3 shows a considerable variation in the standard deviations for the particle counts per frame, some as high as 50%. For many ingots the standard deviation for the particle count is low and essentially zero. This indicates the dependency of graphite morphology and distribution in nodular irons on the operating variables such as casting temperature, composition, magnesium content, and the cooling rate through the eutectic range. The latter is of particular significance when casting small ingots as in the present investigation, for the cooling rate will vary considerably throughout the ingot depending on the position, and therefore the nodule frequency and distribution will correspondingly be variable.

The nodularity can be related to a mean min/max diameter ratio for the particles. The largest value for the mean of the min/max diameter ratio that was obtained is 0.55 (sample A10, Fig. 12a), and this value was arbitrarily defined as a nodularity of 100%. For the zero end of the nodularity scale it might be assumed that the mean value of the min/max diameter ratio for flake graphite could be used. However, this is not a sufficiently reliable standard, since the flake morphology is quite varied, and for some types a relatively high mean min/max diameter value is obtained. For example, the structure of A13, shown in Fig. 12b, is clearly flake, and has a mean min/max diameter ratio of 0.24. It was decided; therefore, to choose arbitrarily a structure that appeared visually to have a nodularity of about 50%, and to use the corresponding mean value of the min/max diameter ratio to establish the nodularity scale. The structure of sample A24, shown in Fig. 12 c, which has a mean min/max diameter ratio of 0.34 was thus arbitrarily assigned a nodularity of 50%. In performing the image analysis, it is necessary to set in the computer program a limiting range for the min/max diameter ratio (aspect ratio), which was taken as $0.05 < \xi < 0.95$. Using the above, arbitrarily defined criteria, the nodularity scale of Table 6 was constructed.

Since the quality of the nodular iron is strongly dependent on the graphite nodule count (total number of particles/mm^2) as well as the shape, a relative nodularization index is next (arbitrarily) defined as follows:

Relative Nodularization Index $=$ (Nodule count) $\times$ (% of total number of particles which have a min/max diameter ratio $\geq$ 0.5)

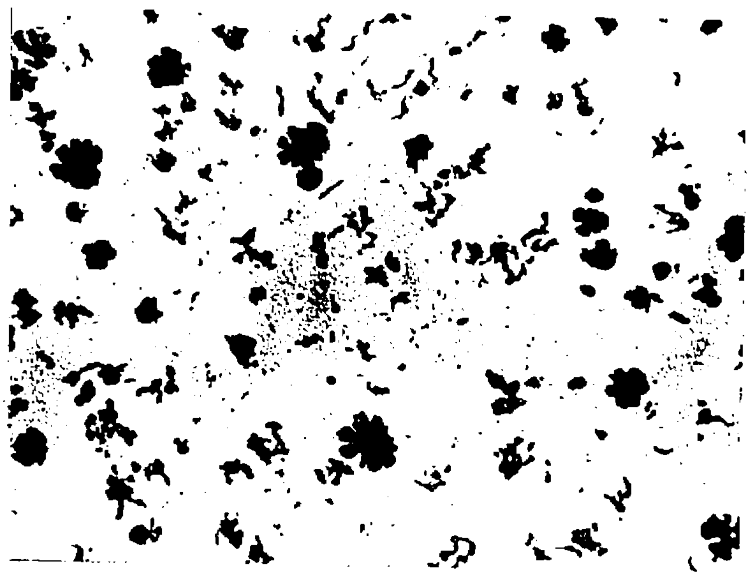


100X

Fig. 12a. Microstructure of sample A10
Residual magnesium: 0.086%
Mean min/max diameter ratio: 0.55
Nodularity: 100%
Normalized Nodularization Index: 69

100X

Fig. 12b. Microstructure of sample A13
Residual magnesium: 0.001%
Mean min/max diameter ratio: 0.24
Nodularity: 0%
Normalized Nodularization Index: 0



100X

Fig. 12c. Microstructure of sample A24
Residual magnesium: 0.002%.
Mean min/max diameter ratio: 0.34
Nodularity: 50%
Normalized Nodularization Index: 23

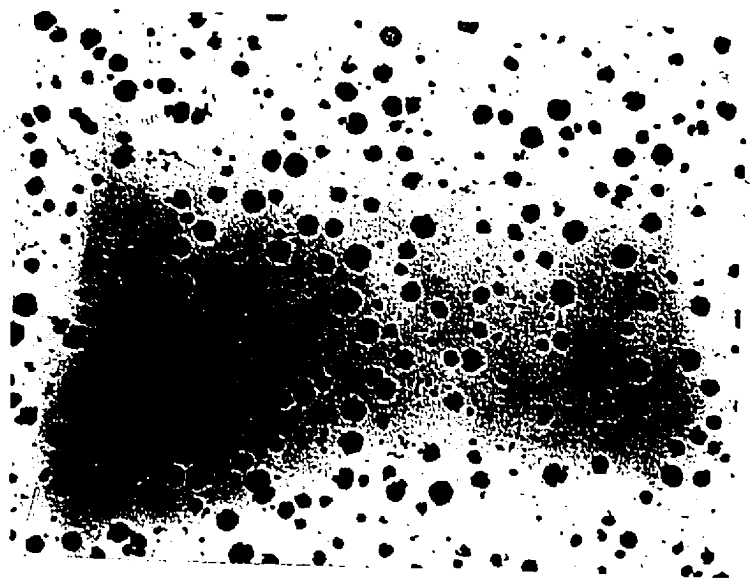
Mean min/max diameter ratio (ξ)	Nodularity %
0.55 - 0.54	100
0.53 - 0.52	95
0.51 - 0.50	90
0.49 - 0.48	85
0.47 - 0.46	80
0.45 - 0.44	75
0.43 - 0.42	70
0.41 - 0.40	65
0.39 - 0.38	60
0.37 - 0.36	55
0.35 - 0.34	50

Table. 6. Nodularity Scale

The relative nodularization index is then normalized against the highest index value obtained, 39,870 for ingot A30 shown in Fig. 13, thus assigning an index of 100 for A30 as the standard against which the other ingots are compared. As an example of the application of the above nodularity and nodularization index scale, the nodularity and normalized nodularization index values for the structures of the A2 series of ingots are indicated in Fig. 14a - 14d. Table 7 gives the summarized results of those ingots listed in Appendix 4 that showed significant retardation in magnesium fade and maintenance of nodularity. These results will now be discussed in the approximate chronological order in which the research progressed.

D. Chloride Salt Constituent

The earlier results obtained in developing a method of incorporating the magnesium containing ferrosilicon into the cast iron melt, i.e. using molten salt covers as protection against the atmosphere, established that $BaCl_2$, $CaCl_2$ and NaCl, were all effective in eliminating or greatly reducing the pyrotechnics usually associated with the process. However, barium chloride is preferred to the other two salts because of its relatively low fuming tendency at normal foundry working temperatures. $BaCl_2$ has a boiling point of about 1560 C, which is about 50-100 C above the melt temperatures usually encountered. The boiling point of $CaCl_2$ is also in the range 1560-1600 C, but

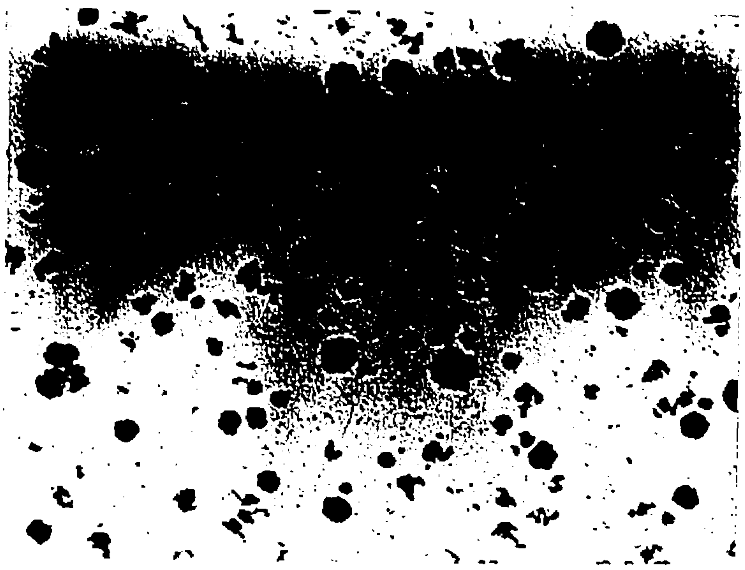


100X

Fig. 13. Microstructure of sample A30
Residual magnesium: 0.059%
Mean min/max diameter ratio: 0.51
Nodularity: 90%
Normalized Nodularization Index: 100

100X

Fig. 14a. Microstructure of sample A20
which was held at 1470 C for 0 time
Residual magnesium: 0.102%
Mean min/max diameter ratio: 0.48
Nodularity: 85%
Normalized Nodularization Index: 66

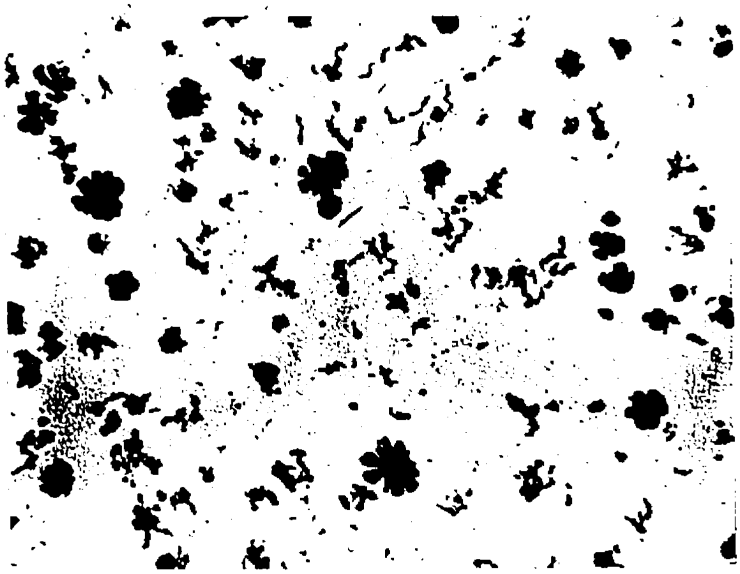


100X

Fig. 14b. Microstructure of sample A21
which was held at 1470 C for 5 minutes
Residual magnesium: 0.026%
Mean min/max diameter ratio: 0.45
Nodularity: 75%
Normalized Nodularization Index: 41

100X

Fig. 14c. Microstructure of sample A22
which was held at 1470 C for 10 minutes
Residual magnesium: 0.002%
Mean min/max diameter ratio: 0.43
Nodularity: 70%
Normalized Nodularization Index: 33



100X

Fig. 14d. Microstructure of sample A24
which was held at 1470 C for 20 minutes
Residual magnesium: 0.002%
Mean min/max diameter ratio: 0.34
Nodularity: 50%
Normalized Nodularization Index: 23

Sample No.	FeSiMg /$BaCl_2$ (gm)	Inocu-lant (gm)	Slag/gm	Temp. (C)	Holding Time (min)	Residual Mg%	Nodule Count (No./mm^2)	Nodul-arity %	Normalized Nodulariza-Index
A10 (F*)	4/4	-	-	1500	0	0.086	400	100	69
A11 (F*)	4/4	-	-	1500	5	0.038	379	95	61
A12 (F*)	4/4	-	-	1500	10	0.003	292	60	24
A13 (F*)	4/4	-	-	1500	15	0.001	0	0	0
A20 (F*)	4/4	-	-	1470	0	0.102	450	85	66
A21 (F*)	4/4	-	-	1470	5	0.026	311	75	41
A22 (F*)	4/4	-	-	1470	10	0.002	280	70	33
A24 (F*)	4/4	-	-	1470	20	0.002	334	50	23
A30 (F*)	4/4	-	-	1400	0	0.059	637	90	100
A31 (F*)	4/4	-	-	1400	5	0.003	361	60	37
A32 (F*)	4/4	-	-	1400	10	0.002	305	70	34
A33 (F*)	4/4	-	-	1400	15	0.011	253	75	32

Table 7. The Results of Residual Mg Content, Nodule Count, Nodularity and Normalized Nodularization Index (Summarized from Appendix 4)
Legend: F: Ford material; H: Hanna material; B: Bendix material
*: Fast cool; **: Slow cool

Sample No.	FeSiMg /$BaCl_2$ (gm)	Inoculant (gm)	Slag/gm	Temp. (C)	Holding Time ø (min)	Residual Mg%	Nodule Count (No./mm^2)	Nodularity %	Normalized Nodularization Index
A34 (F*)	4/4	-	-	1400	20	0.003	351	75	46
A40 (F*)	4/4	-	-	1350	0	0.140	504	85	77
A41 (F*)	4/4	-	-	1350	5	0.013	499	70	53
A43 (F*)	4/4	-	-	1350	15	0.007	391	75	44
A45 (F*)	4/4	-	-	1350	30	0.012	240	70	27
YY3 (F*)	4/4	-	I/4	1500	20	0.040	333	100	56
YY42 (F**)	4/4	-	I/4	1500	20	0.035	254	60	26
YY45 (F**)	4/4	-	I/4	1500	20	0.039	255	70	31
YY41 (F**)	4/4	-	I-1/4	1500	20	0.035	328	75	37
YY43 (F**)	4/4	-	I-2/4	1500	20	0.035	345	80	43
YY46 (F**)	4/4	-	I-2/4	1500	20	0.042	211	80	28
YY55 (F**)	4/4	-	I-2/4	1500	20	0.060	264	65	26
YY67 (F**)	4/4	-	II-3/4	1500	20	0.071	478	90	72
YY68 (F**)	4/4	1	II-3/4	1500	20	0.069	430	85	64
YY71 (F**)	4/4	1	II-3/4	1550	20	0.100	342	70	44

Table 7. Cont'd

Sample No.	FeSiMg /$BaCl_2$ (gm)	Inocu- lant (gm)	Slag/gm	Temp. (C)	Holding Time (min)	Residual Mg%	Nodule Count (No./mm^2)	Nodul- arity %	Normalized Nodulariza- Index
YY72 (F**)	4/4	1	II-3/4	1500	30	0.053	302	80	42
YY75 (F**)	4/4	1	II-3/4	1500	0	0.100	541	95	87
YY76 (F**)	4/4	1	II-3/4	1500	5	0.085	412	80	56
YY77 (F**)	4/4	1	II-3/4	1500	15	0.082	417	95	66
YY86 (H**)	4/4	1	II-3/4	1500	20	0.066	429	80	56
YY89 (H**)	4/4	1	II-3/4	1500	20	0.092	447	90	70
YY90 (F**)	4/4	1	II-3/4	1500	20	0.198	365	85	51
YY92 (F*)	4/4	1	II-3/4	1500	20	0.220	470	90	71
YY98 (F**)	4/4	1	II-4/4	1500	20	0.055	399	85	55
YY104(F**)	4/4	1	II-7/4	1500	20	0.082	392	80	50
YY105(F**)	4/4	1	II-7/4	1500	20	0.024	451	75	53
YY124(F**)	4/4	-	II-7/4	1500	20	0.033	389	95	62
YY106(F**)	4/4	1	II-8/4	1500	20	0.045	365	80	50
YY125(F**)	4/4	-	II-8/4	1500	20	0.042	359	80	46
YY108(F**)	4/4	1	II-10/4	1500	20	0.038	320	80	42

Table 7. Cont'd

Sample No.	FeSiMg $/BaCl_2$ (gm)	Inoculant (gm)	Slag/gm	Temp. (C)	Holding Time (min)	Residual Mg%	Nodule Count (No./mm^2)	Nodularity %	Normalized Nodularization Index
YY126(F**)	4/4	-	II-10/4	1500	20	0.028	360	65	37
YY113(F**)	4/4	1	II-16/4	1500	20	0.055	360	85	52
YY123(F**)	4/4	-	II-16/4	1500	20	0.036	575	80	80
YY18 (F*)	4/4	-	IV/4	1500	20	0.006	-	-	-
YY19 (F*)	4/4	-	V/4	1500	20	0.013	-	-	-

Table 7. Cont'd

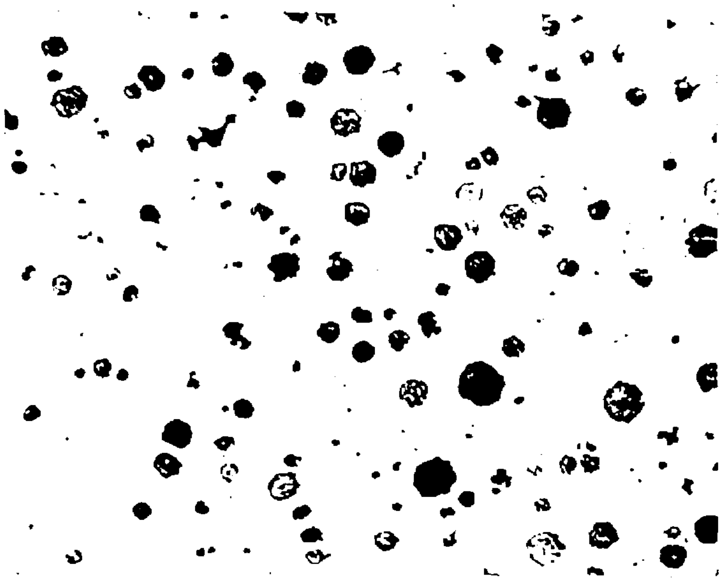
its fuming rate at 1500 C was found to be very much greater than that of $BaCl_2$, thus presenting an environmental contamination problem. Likewise with NaCl, which boils at about 1410 C, the boiling and fuming at 1500 C was extreme and presented a safety problem. For these reasons $BaCl_2$ was selected as the medium or matrix for most of the various chloride salt-alloy composites investigated as possible slags for preventing or inhibiting magnesium loss from cast iron melts.

E. Magnesium Loss Rate in Slag-Free Melts

To determine the effectiveness of a particular slag in preventing or retarding the rate of volatilization loss of magnesium from cast iron melts, it was necessary to first establish the rate of loss from slag-free melts as a standard for comparison. The A series of ingots (cf. Table 7) were investigated for this purpose over a series of temperatures (1350 C, 1400 C, 1470 C, 1500 C) and holding times (0-20 min.). The residual magnesium results obtained for the above ingots can not be used to establish an exact quantitative expression for the time rate of loss of magnesium, since the residual magnesium content for any given temperature and holding time will depend on the amount of magnesium incorporated initially, and this will inevitably vary. For example, for the A1 series of ingots, the amount of magnesium incorporated initially (0 time) varies from 0.059% (1400 C) to 0.140% (1350 C). It is evident, however, that the rate of magnesium loss is rapid, and that after 5 minutes at least 50% of the initial magnesium incorporated is lost. This is in approximate agreement with the results given by Robinson et al[8] (see Fig. 5), which show that about 50% of the magnesium is lost after a 5 minute holding period. In the present investigation the melt surfaces were covered with a blanket of the residual chloride salt from the charging procedure. The fact that the rate of magnesium loss does not differ significantly from that found by others investigating slag-free melts shows that the chloride salt cover in itself does not provide any significant protection against magnesium loss from melts. Figure 14a to 14d show the microstructures of the A20 to A24 ingots, which were held at 1470 C for various times without any slag layer (except the residual $BaCl_2$ slag cover). The decreases in nodularity and the magnesium content with time is readily evident. The maximum amount of magnesium that can be initially incorporated is about 0.10%. After 5 minutes, the residual magnesium is ~ 0.026%, and many nodules are developing spikes and irregular shapes in general (vermicular graphite). As the holding time increases to 20 minutes the residual magnesium has dropped to about 0.002%, and reversion of the graphite to a flake morphology is well advanced. A good nodularity (and nodularization index) is obtained when the residual magnesium content is about 0.03% and higher. Some ingots show a relatively good nodularization index for magnesium levels down to 0.01%, however, ingot consistency and reproducibility are generally poor when the residual magnesium level falls below 0.03%.

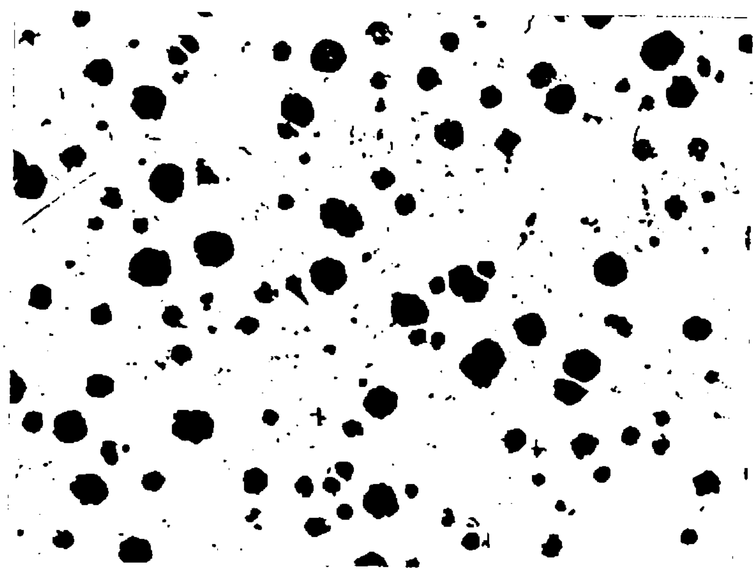
F. Magnesium Loss Rate in Slag-Covered Melts

The rate of magnesium loss is significantly retarded from those melts covered with chloride salt-silicon alloy slag composites. This is evident from the residual magnesium and nodularization index results obtained for these ingots as shown in Table 7. The residual magnesium of ingots which were covered by $CaCl_2$-silicon alloy composites, held at 1500 C for 20 minutes is around 0.035% (cf. YY3, YY41, YY42, YY43, YY45, YY46 and YY55). Figure 15 shows the ingot (YY3) microstructure for a melt covered with slag I, which is a $CaCl_2$-silicon alloy composite (cf. Table 5). A good nodularity (100%) and normalized nodularization index (56) are obtained for a corresponding residual magnesium level of 0.040%. For melts covered by $BaCl_2$-silicon alloy slags the residual magnesium levels were higher, in some cases exceeding 0.19% (cf. YY67, YY68, YY71, YY86, YY89, YY90, YY92, YY104 and YY113). This indicates that $BaCl_2$-base slags are more effective in preventing magnesium fade than $CaCl_2$-base slags. Figures 16a and 16b show the microstructures obtained for ingots protected by $BaCl_2$-base slags containing FeSiMg alloy. When compared to Fig. 15, it is evident that the improvement in nodularity and nodularization index is not significant when the residual magnesium level of about 0.04% is exceeded (YY92 has a residual magnesium level of 0.220% compared to 0.040% for YY3). It should be pointed out that the microstructures shown will not necessarily agree with the given nodularity and nodularization indices, due to the



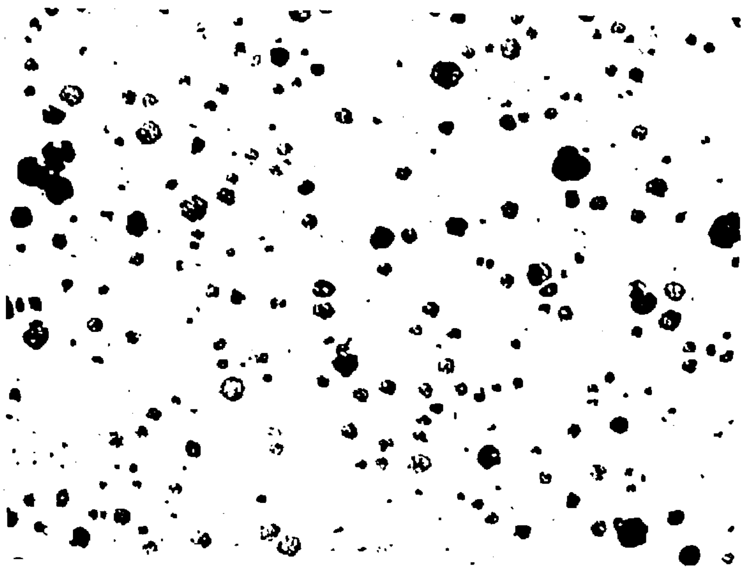
100X

Fig. 15. Microstructure of sample YY3 which was covered by slag I, held at 1500 C for 20 minutes
Residual magnesium: 0.040%
Mean min/max diameter ratio: 0.54
Nodularity: 100%
Normalized Nodularization Index: 56



100X

Fig. 16a. Microstructure of sample YY89 which was covered by slag II-3, held at 1500 C for 20 minutes
Residual magnesium: 0.092%
Mean min/max diameter ratio: 0.51
Nodularity: 90%
Normalized Nodularization Index: 70

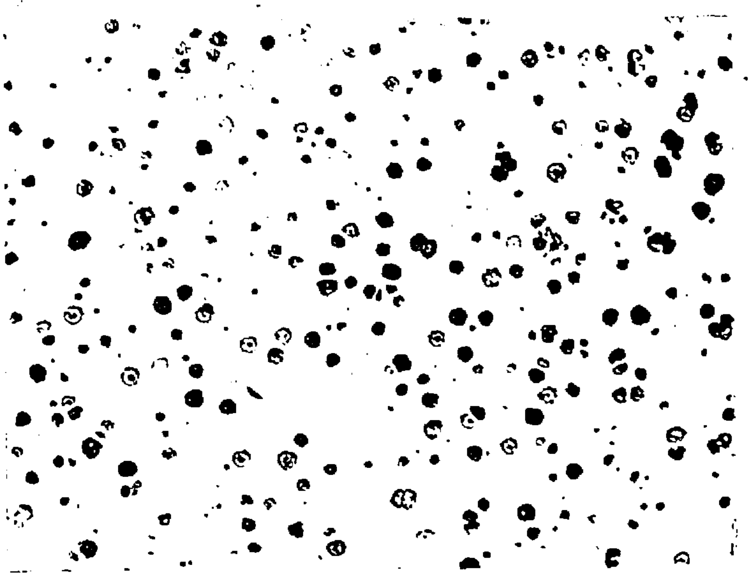


100X

Fig. 16b. Microstructure of sample YY92 which was covered by slag II-3, held at 1500 C for 20 minutes
Residual magnesium: 0.220%
Mean min/max diameter ratio: 0.50
Nodularity: 90%
Normalized Nodularization Index: 71

latter representing averages computed from 5 areas, while the microstructures represent one specific area in the ingot. The results of Table 7 show that melts covered with chloride salt-silicon alloy composite slags significantly retard the rate of magnesium loss, and that good nodularity may be retained for ingots maintained at temperature and times exceeding 1500 C and 30 minutes respectively. For most ingots a holding time of 20 minutes at a temperature of 1500 C was used to determine the slags effectiveness, since slag-free melts under these conditions effectively lost all magnesium. It was not practical to extend the holding time beyond 20 minutes due to the excessive oxidation loss of the crucible material.

The results show that all ingots protected by a chloride-salt slag containing a silicon alloy show high residual magnesium content and good nodularity, indicating that Si is the component in the slag which prevents magnesium fade from the melts. In order to determine the effect of Si alone in the chloride salt on inhibiting magnesium fade, $BaCl_2$-Si powder composites of varying Si content were tested. Generally, the most effective slag is the one which contains about equal amounts of $BaCl_2$ and Si (slags II-10 and II-16). Figure 17 shows the excellent nodularity that is maintained by the ingot when the melt is protected with a $BaCl_2$-50% Si slag composite. If the Si content is too low, e.g. 10% Si in slag II-13 and 5% Si in slag II-14, the magnesium fade rate is only slightly retarded, and the residual



100X

Fig. 17. Microstructure of sample YY123 which was covered by slag II-16, held at 1500 C for 20 minutes
Residual magnesium: 0.036%
Mean min/max diameter ratio: 0.47
Nodularity: 80%
Normalized Nodularization Index: 80

magnesium content decreased to above 0.01% or lower (cf. YY110 and YY111). However, if the chloride salt content of the slag is too low, the slag is not sufficiently fluid to spread quickly and uniformily across the melt surface, and the protection afforded by the slag is poorer. For example, the melts of ingots YY18 and YY19 were protected by slags IV and V respectively, which contained only 39% chloride salt, and the corresponding residual magnesium values after 20 minutes at 1500 C are 0.006% and 0.013% respectively. The prevention of magnesium fade also depends on the amount of slag used. For the 100 gm metal charges used in this investigation, 4 gm of slag composite powder was applied in most of the tests. It was found that as little as 2 gm of slag was sufficient to provide protection, although the results tended to become rather erratic. For example, YY73, which was covered by only 2 gm of slag II-3, shows a residual magnesium content of 0.015% after the melt was held at 1500 C for 20 minutes.

The inclusion of magnesium in the silicon alloy component of the chloride salt-silicon alloy composite slag does not improve the slag's effectiveness in retarding the rate of magnesium loss from the melts. Slags containing the nodularizer, (which is a ferrosilicon alloy containing about 5% Mg) for the silicon alloy component were no more effective in maintaining nodularity than slags containing no magnesium in the silicon alloy component. This suggests that the slag is rapidly saturated with magnesium from the melt, which then provides the "back pressure" of magnesium to counter the magnesium pressure in the melt. Several other constituents were added to the chloride salt to explore their effectiveness in retarding magnesium fade, e.g. MgO, CaO, SiO_2, Al_2O_3, Ce_2O_3, CaSi and $MgCl_2$ (see Table 5 and Appendix 4). In general there was no significant improvement in the protection afforded by the chloride salt-silicon alloy slag composite.

G. Proposed Mechanism for The Slag Behaviour

The solubility of magnesium in liquid iron is exceedingly small. Nevertheless, the vapor pressure of magnesium at 1500 C is considerable due to its relatively low boiling point (1120 C). If the liquid Fe-Mg system behaved ideally, which is not the case, the vapor pressure of magnesium above a cast iron melt containing 0.04% magnesium would be about 0.011 atmospheres, as given by Raoult's law,

$$P_{Mg} = P^{\circ}_{Mg} \quad N_{Mg}$$

where P°_{Mg} is the vapor pressure of pure Mg at 1500 C ($\sim$13.6 atmospheres - cf. Fig.4) and N_{Mg} is the mole fraction of Mg corresponding to 0.04% in the liquid iron,

Mg:	0.04 gm	0.04/24.32	= 0.0016	mole
Si:	3.0 gm	3.0/28.06	= 0.1069	mole
C :	3.46 gm	3.46/12	= 0.2883	mole
Fe:	93 gm	93/55.84	= 1.6654	mole
		total	2.0622	mole

$$N_{Si}^{Fe} \doteq 0.1069/2.0622 \doteq 0.0518$$

$$N_{Mg}^{Fe} = 0.0016/2.0622 = 0.0008$$

The situation is considerably less favorable for the retention of magnesium than the above assumption allows, since the Fe-Mg system is known to exhibit a substantial positive deviation from Roalt's law. Guichelaar et. al.[39] have determined the magnesium activity coefficient at 1455 C as a function of silicon content for liquid compositions lying on the immiscibility curve (corresponding to a magnesium variation from $\sim$0.8% to 7.0%), which is shown in Fig. 18. For a cast iron containing about 3% Si ($N_{Si} \sim 0.0518$), Fig. 18 gives $\gamma_{Mg}^{Fe} \sim 70$, so that the vapor pressure of magnesium is correspondingly increased according to Henry's law, $P_{Mg} = \gamma_{Mg}^{Fe} N_{Mg}^{Fe} P_{Mg}^{\circ}$, which gives $P_{Mg} \sim 0.76$ atmospheres for a 0.04% magnesium level in cast iron melt. Thus the reason for the rapid loss of magnesium from a cast iron melt at 1500 C is readily evident, viz., the relatively high equilibrium vapor pressure of the magnesium above the liquid cast iron alloy.

Thermodynamics requires that the chemical potential of magnesium in a slag applied to the surface of a cast iron melt (containing magnesium) be equilibrated, and this would occur initially at the interface and then spread throughout the slag by diffusion and convection. Finally, after equilibration, the magnesium vapor pressure above the slag would be equal to that above the melt, which for a 0.04% magnesium concentration

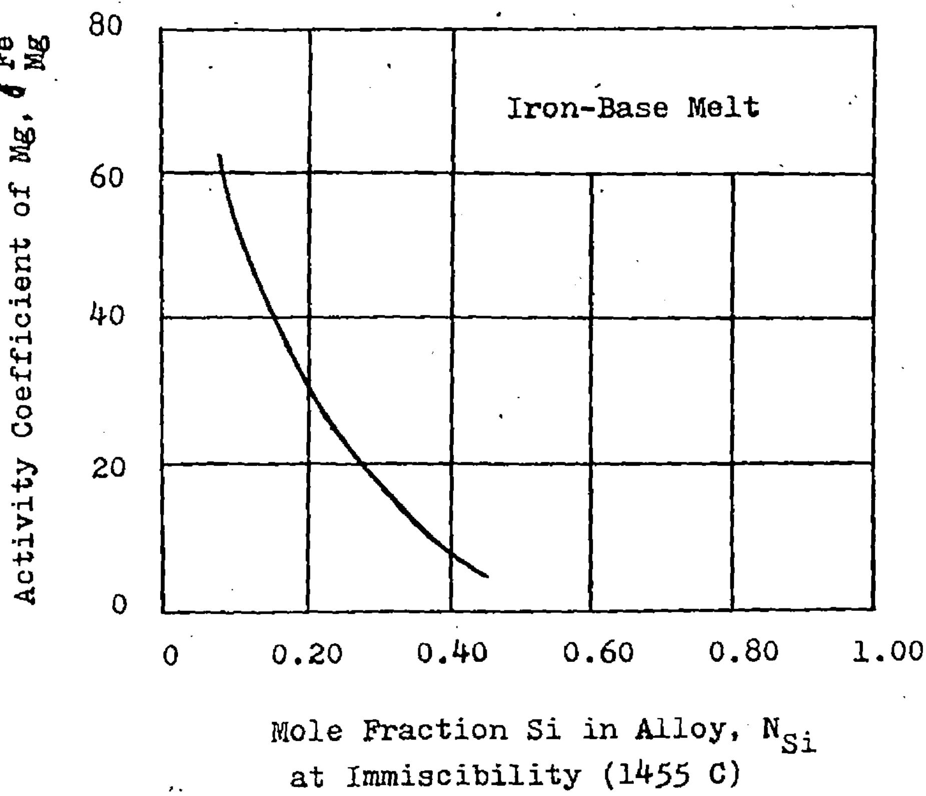


Fig. 18. Activity coefficient of Mg at 1455 C as a function of Si concentration in Fe-Si-Mg alloys lying on the immiscibility curve. (after Guichelaar and Trojan[39])

is estimated above to be about 0.76 atm. Although the slag application does not appear to be beneficial from a thermodynamical standpoint, the kinetics of the magnesium transfer may be considerably slowed down as the following consideration will show.

The X-ray diffraction results show that in the solid state there is little or no solubility of elemental magnesium or silicon in $BaCl_2$. This is also supported by the absence of any evidence in the literature of compounds or minerals of $BaCl_2$ containing magnesium or silicon. Of course, in the liquid state (1500 C) there may well be some solubility of magnesium or silicon in $BaCl_2$, but the chemical incompatability of the slag-metal system would seem to suggest that the solubility is indeed low. The molten slag composite would appear to be a suspension or colloidal-type system. Thus, the slag would absorb very little magnesium from the melt in the process of equilibrating the chemical potentials, and if the activity coefficient, γ_{Mg}^{slag}, is as high as γ_{Mg}^{Fe}, the concentration absorbed would be of the order of that in the cast iron melt. If activity coefficient $\gamma_{Mg}^{slag} \gg \gamma_{Mg}^{Fe}$, then the concentration of magnesium absorbed in the slag would be correspondingly lower than that in the cast iron melt.

After equilibration of the slag, magnesium loss from the melt would be controlled by the diffusion rate through the slag layer, provided that the vapor pressure of the magnesium did not exceed 1 atmosphere, (at which a rapid boiling transfer would result) and there was little convective transfer. The first condition, viz., that $P_{Mg} < 1$ atm, appears to be present for melts containing about 0.04%-0.05% magnesium. The second condition, viz., no convective transfer, would be favored in high viscosity slags. The slags containing relatively high Si contents exhibit a high viscosity, and thus would tend to inhibit excessive convective action. The time required for diffusion through a slag layer may be estimated from the relationship $(\bar{x})^2 \approx Dt$, where $\bar{x}$ is the mean diffusion distance, D the diffusion constant and t the time. Thus assuming $D \sim 10^{-4}$ cm^2/sec in the liquid slag, $\bar{x} \sim 1$ cm, the time interval is 10^{-4} sec or about 2 hours. The above is an order of magnitude calculation, and several factors would tend to accelerate the process. Nevertheless, it is evident that the rate of magnesium loss from the melt can be significantly retarded, and is a plausible explanation for the protection of the chloride salt-silicon slags provided in this investigation.

The results show that Si is a key constituent in the slag, and in its absence the chloride salt cover had little or no effect in retarding the rate of magnesium fade. The role of silicon may be twofold: (a) increasing the viscosity of the slag as discussed above, and so inhibiting convective transfer, and (b) providing a sink for magnesium by reacting with magnesium to form a Mg_2Si compound (liquid) which remains in the slag to provide the required magnesium potential.

V. CONCLUSIONS

The results of this investigation show that chloride salt-silicon alloy composite slags are effective in retarding the rate of volatilization loss of magnesium from cast-iron melts at temperatures up to 1550 C and holding times up to at least 30 minutes. The decreased rate of magnesium loss, as measured by the higher residual magnesium levels of the ingots, results in a corresponding improvement in the nodularity of the graphite. The $BaCl_2$-Si composite slags, containing approximately 50% by weight of each constituent, are the most effective, but slags varying considerably from this salt/silicon ratio also provide good protection. The mechanism by which the slag provides the protection has not been determined, but a consideration of the thermodynamics and kinetics of the system suggests that diffusion transport of the magnesium through the viscous slag layer is the slow and rate inhibiting stage of the volatilization process. However, to establish the actual mechanism by which the chloride salt-silicon alloy composite slag prevents magnesium fade from the cast iron melt, further experiments are required in which the variables such as slag depth, temperature, and composition are more rigorously controlled, and accurate diffusion constants used.

BIBLIOGRAPHY

1. J. Gerin Sylvia, Cast Metal Technology, p. 234-235, 1972.
2. J. E. Hiliard and W. S. Owen, "A Thermal and Microscopic Study of the Iron-Carbon-Silicon System," Journal of The Iron and Steel Institute, vol. 172, p. 268-282, 1952.
3. Rehder, AFA Transaction, 1947.
4. J. Keverian, H. F. Taylor and J. Wulff, "Experiments on Spherulite Formation in Cast Iron," American Foundryman, vol. 23, p. 85-91, 1953.
5. J. Keverian and H. F. Taylor, "Effects of Gaseous and Solid Addition Elements on Surface Tension and Contact Angle (on Graphite) of Various Iron-Carbon Alloy," Trans. AFS, vol 65, p. 212-221, 1957.
6. R. H. McSwain, C. E. Bates and W. D. Scott, "Iron-Graphite Surface Phenomena and Their Effect on Iron Solidification," AFS Transactions, vol. 82, p. 85-94, 1974.
7. I. E. Bolotov, V. I. Syreischikova and S. G. Futerman, "Formation Mechanism of Graphite Spherules in Cast Iron," Growth of Crystals, vol. 1, Chapman and Hall, Ltd., New York, 1959.
8. M. Robinson, "Mg Bearing Postinoculant with 90 to 100% Mg Recovery for Production of Ductile Iron," AFS Transactions, vol. 84, p. 585-592, 1976.
9. P. K. Trojan and R. A. Flinn, "Fundamentals of Mg Addition to Ductile Iron," SAE Transactions, 1965.

10. E. A. Spengler and H. K. Briggs, "The Ductile Iron Process Compendium IV," Miller and Company, 1972.

11. G. S. Cole, "Solidification of Ductile Iron," AFS Transactions, vol. 80, p. 335-348, 1972.

12. D. Matter, H. H. Wilder, "Factors Affecting Application and Behavior of Mg Additives for Ductile Iron," AFS Transactions, vol. 71, p. 625-627, 1963.

13. R. Carlson, "Experiences with Plunging, Open Ladle and Sandwich Methods," AFS Trans., vol 71, p. 638-640, 1963.

14. AFS Committee 12H, Modern Casting, vol. 52, p. 110-111, 1967.

15. R. W. White, "Application of Sandwich Method to Produce Ductile Iron," AFS Trans. vol. 71, p. 628-631, 1963.

16. M. Remondino, F. Pilastro, "Inoculation and Spheroidizing Treatments Directly Inside the Mold," AFS Trans. vol. 82, p. 239-252, 1974.

17. N. C. McLure, A. U. Khan, D. D. McGrady and H. L. Womochel, "Inoculation of Gray Cast Iron: Relative Effectiveness of Some Silicon Alloys and Active Metals as Ladle Additions," AFS Trans., vol. 65, p. 340-351, 1957.

18. J. V. Dawson, "Factors Influencing the Inoculation of Cast Iron," BCIRA Journal, vol. 9, No. 2, p. 199-236, March 1961.

19. R. L. Mickeson, "Cerium-silicon Alloy Reduce Chill in Gray Iron," Foundry, vol. 96, No. 6, p. 145-149, June 1967.

20. J. H. Schaum, Modern Castings, vol. 41, p. 134, 1962.

21. H. W. Lownie, "Barium Inoculants Resist Fading," Modern Castings, vol. 91, No. 4, p. 66-68, April 1963.

22. J. V. Dawsin, "Stimulating Effect of Strontium on Ferrosilicon and Other Silicon-containing Inoculants," Modern Castings, vol. 49, No. 5, p. 171-177, May 1966.

23. A. Moore, "Some Factors Influencing Inoculation and Inoculant Fade in Flake and Nodular Graphite Irons," AFS Trans., vol. 81, p. 268-277, 1973.

24. K. M. Htun, "Eutectic and Neo-eutectic Graphite Crystallization in Cast Irons," Ph.D. Thesis, University of Wisconsin, June 1965.

25. S. I. Karsay and A. J. Ridley, "Instantaneous Ladle Inoculation of Gray and Ductile Irons," AFS Trans., vol. 76, p. 151-158, 1968.

26. G. Fr. Hillner, K. H. Kleeman, "Mold Inoculation of Gray and Ductile Cast Iron - New Solutions to Old Problem," AFS Trans. vol. 83, p. 167-172, 1975.

27. W. J. Dell and R. J. Christ, "Chill Elimination in Ductile Iron by Mold Inoculation," Modern Castings, vol. 60, p. 408-416, July 1964.

28. I. I. Jones, "Mold or Instant Inoculation," Foundry Trade Journal, vol. 118, p. 78-80, Jan. 21th, 1965.

29. C. R. Loper, Jr. and R. W. Heine, "The Effect of Processing Variables on Ductile Iron Quality," AFS Trans., vol. 73, p. 488 - 496, 1965.

30. R. Clark and T. McCluhan, "Influence of Mg Content on The Nodularizing Efficiency of Mg-FeSi Alloys," AFS Trans., vol. 73, p. 442 - 445, 1965.

31. K. Strauss, Applied Science in The Casting of Metals, p. 188, 1970.

32. W. F. Shaw and T. Watmough, "Effect of Base Silicon and Postinoculation on Microstructure of Nodular Iron," AFS Trans., vol. 76, p. 380 - 386, 1968.

33. C. R. Loper, Jr. "Processing and Control of Ductile Cast Iron," AFS Trans., vol. 76, p. 1 - 7, 1968.

34. C. K. Donoho, "Molten Cast Iron for Treating to Produce Ductile Iron," Modern Castings, vol. 46, p. 608 - 610, 1964.

35. H. Morrogh, "Influence of Some Residual Elements and Their Neutralization in Mg-treated Nodular Cast Iron," AFS Trans., vol. 60, p. 439 - 452, 1952.

36. C. R. Loper, Jr. and R. W. Heine, "Graphitization and Processing Cycle in Producing Ductile Iron," AFS Trans., vol. 72, p. 495 - 507, 1964.

37. D. R. Askeland and S. S. Gupta, "Effect of Nodule Count and Cooling Rate on The Matrix of Nodular Cast Iron," AFS Trans., vol. 83, p. 313 - 320, 1975.

38. T. L. Capeletti and J. R. Hornaday, "Nodular Iron Shape Factor - A New Approach to Quantifying Graphite Morphology," AFS Trans., vol. 82, p. 59 - 64, 1974.

39. P. J. Guichelaar, P.K. Trojan, "A New Technique for Vapor Pressure Measurement Applied to The Fe-Si-Mg System," Metallurgical Transactions, vol. 2, p. 3305 - 3313, Dec. 1971.

APPENDICES

APPENDIX 1. Calculation of Cooling Rate

The cooling rate through eutectic range in Fig. 11 is calculated as follows:

Chart speed : 5 cm/min

Distance from point A to point B in X-axis : 0.5 cm

Therefore, the solidification time through eutectic range is:

$$\Delta t = \frac{0.5\ \text{cm}}{5\ \text{cm/min}} = 0.1\ \text{min} = 6\ \text{sec}$$

From the conversion table of Pt/Pt-10%Rh thermocouple,

point A : 11.2 m.v. = 1139 C

point B : 12.7 m.v. = 1264 C

$$\Delta T = 1264 - 1139 = 125\ \text{C}$$

Cooling rate through the eutectic range:

$$\frac{\Delta T}{\Delta t} = \frac{125\ \text{C}}{6\ \text{sec}} = 21\ \text{C/sec}$$

APPENDIX 2. X-ray Diffraction Analyses of Slags

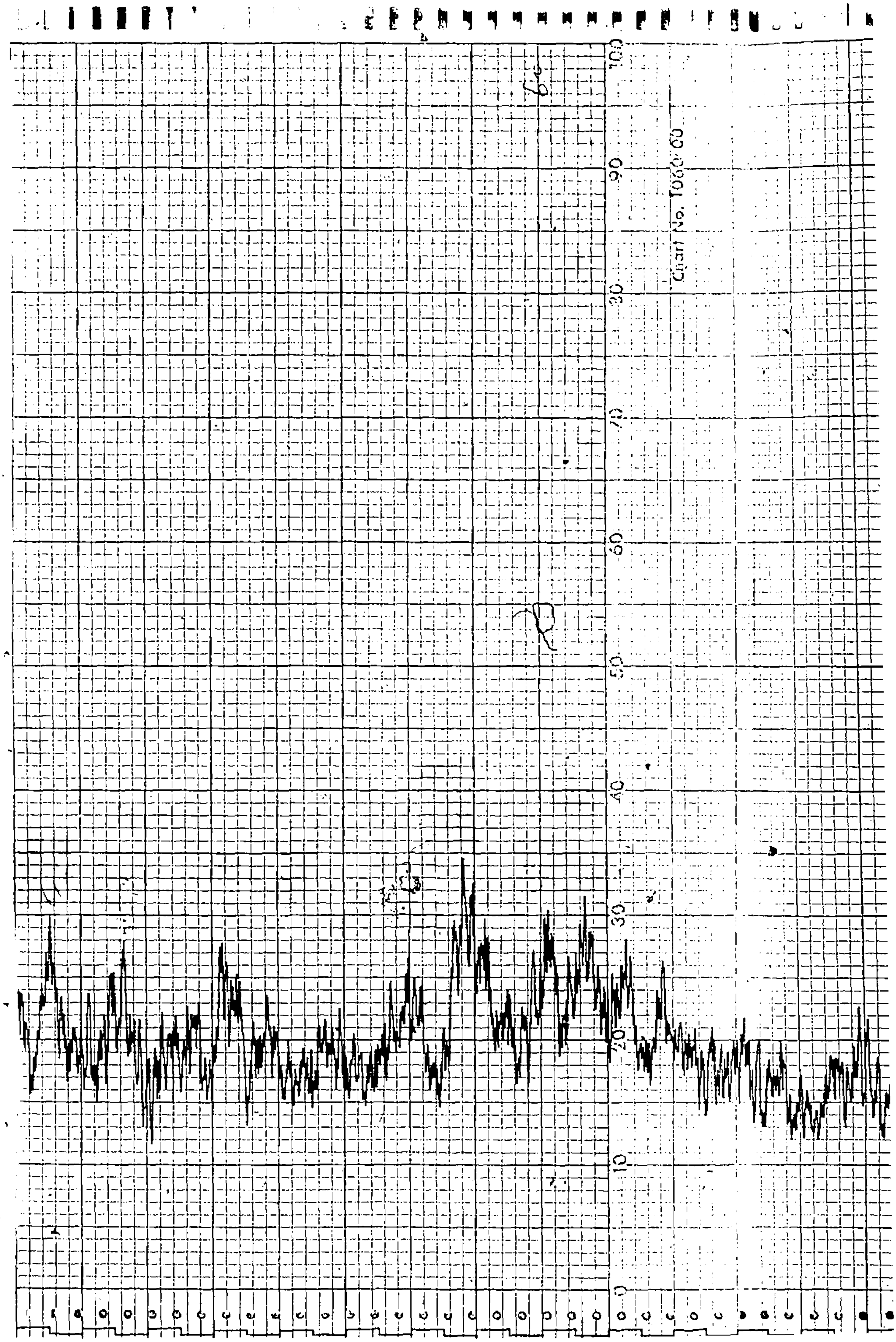
(i) slag II

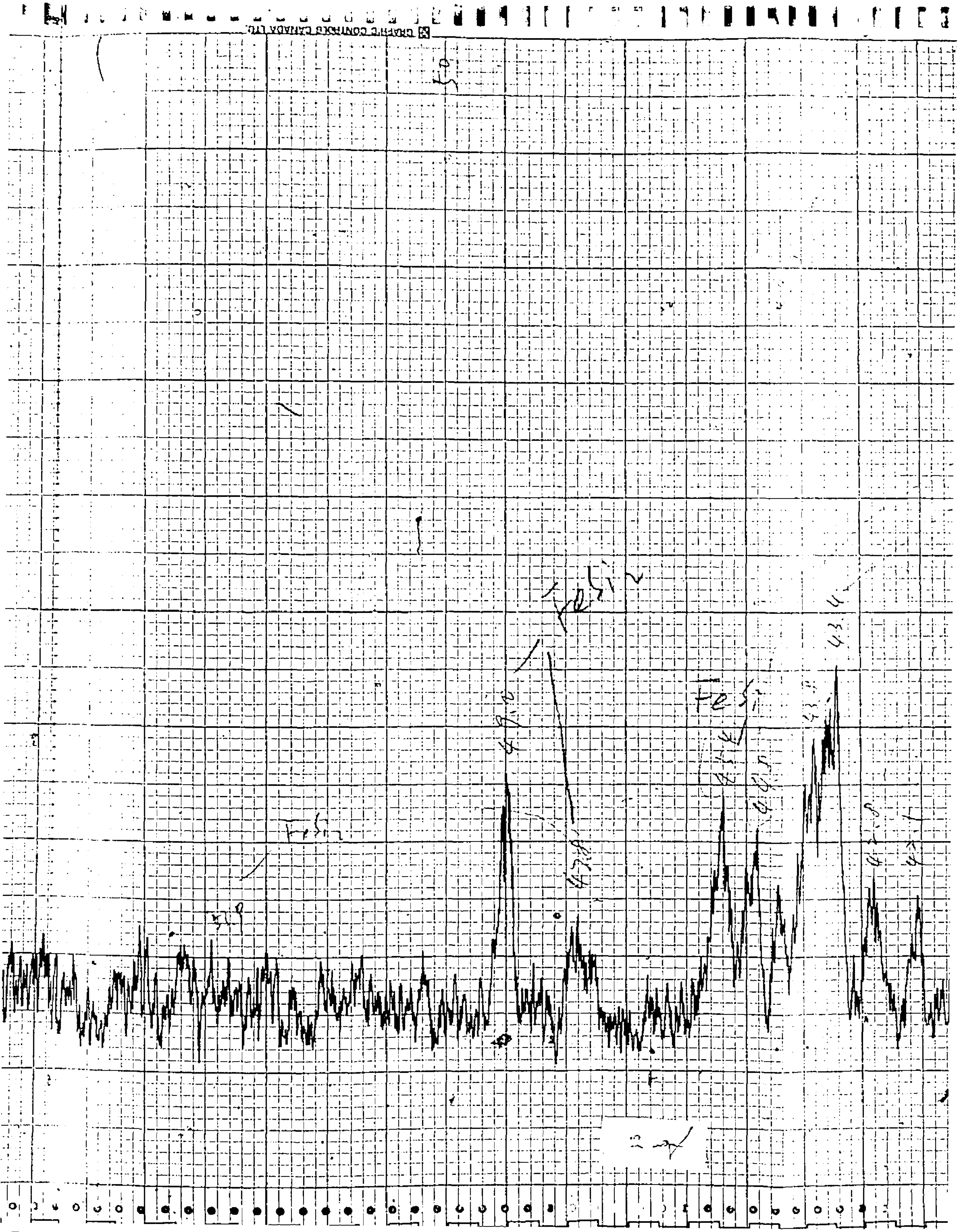
(ii) slag II-3

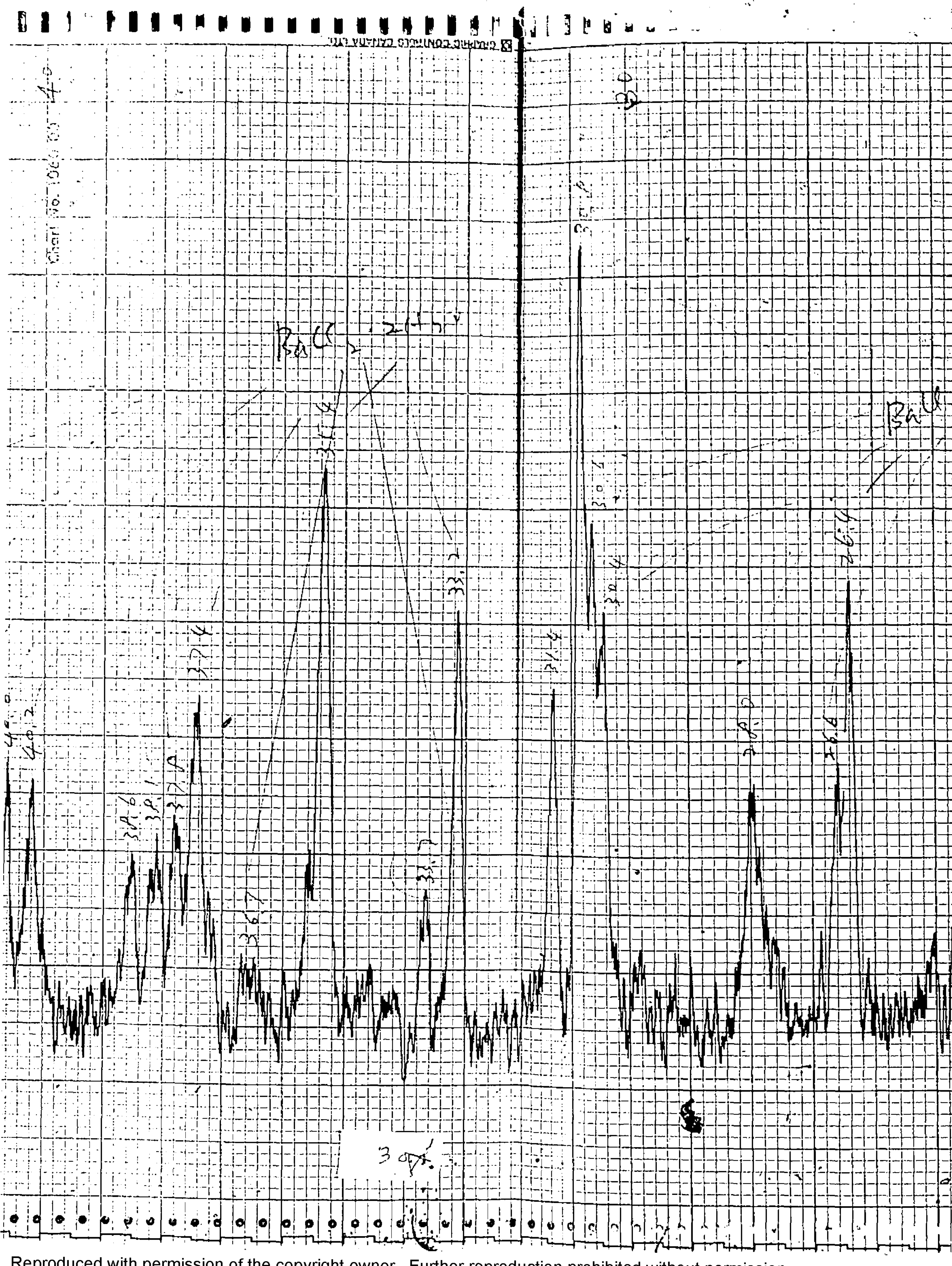
(iii) slag II-13

(iv) slag II-16

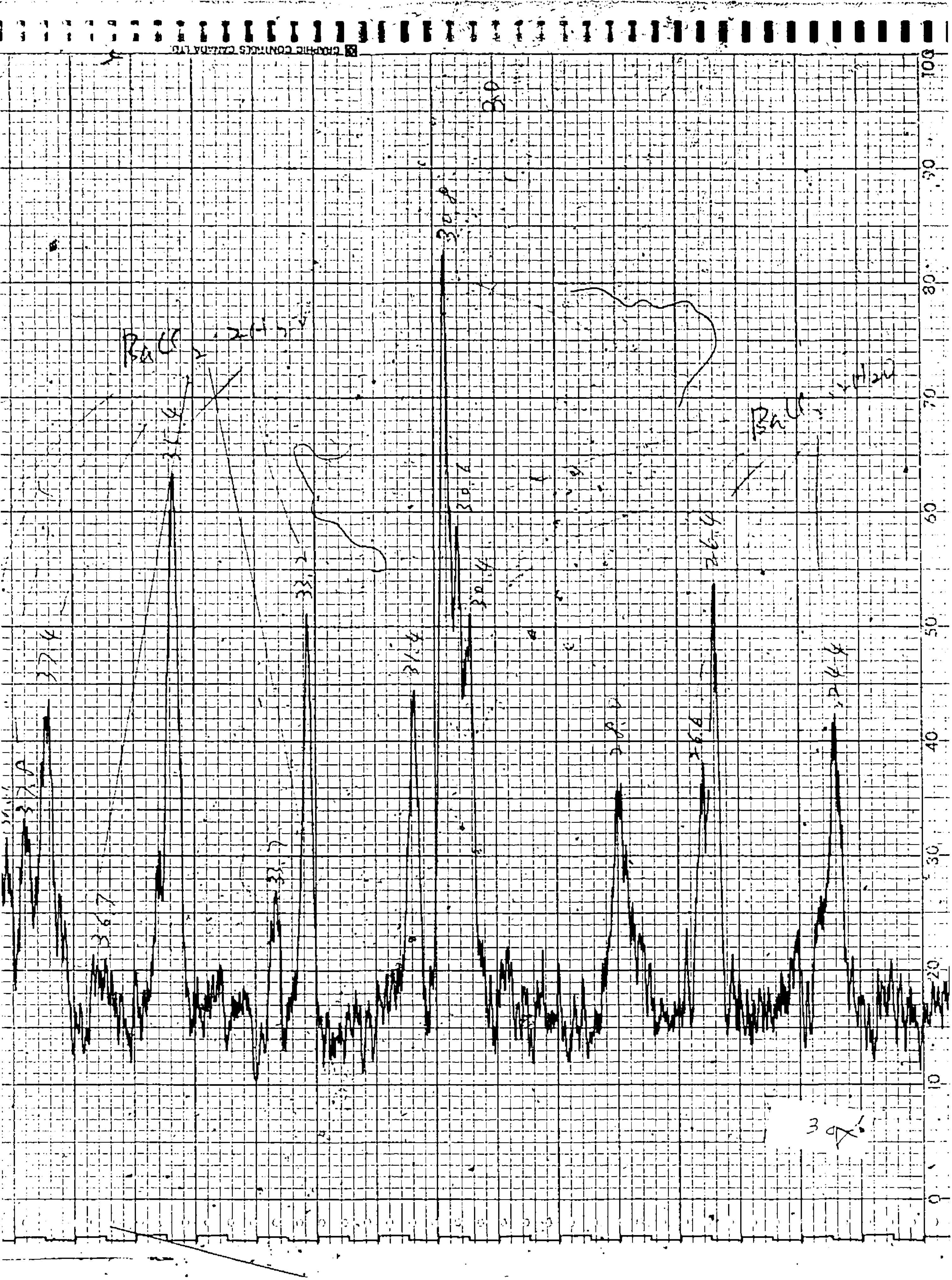
(v) silicon powder

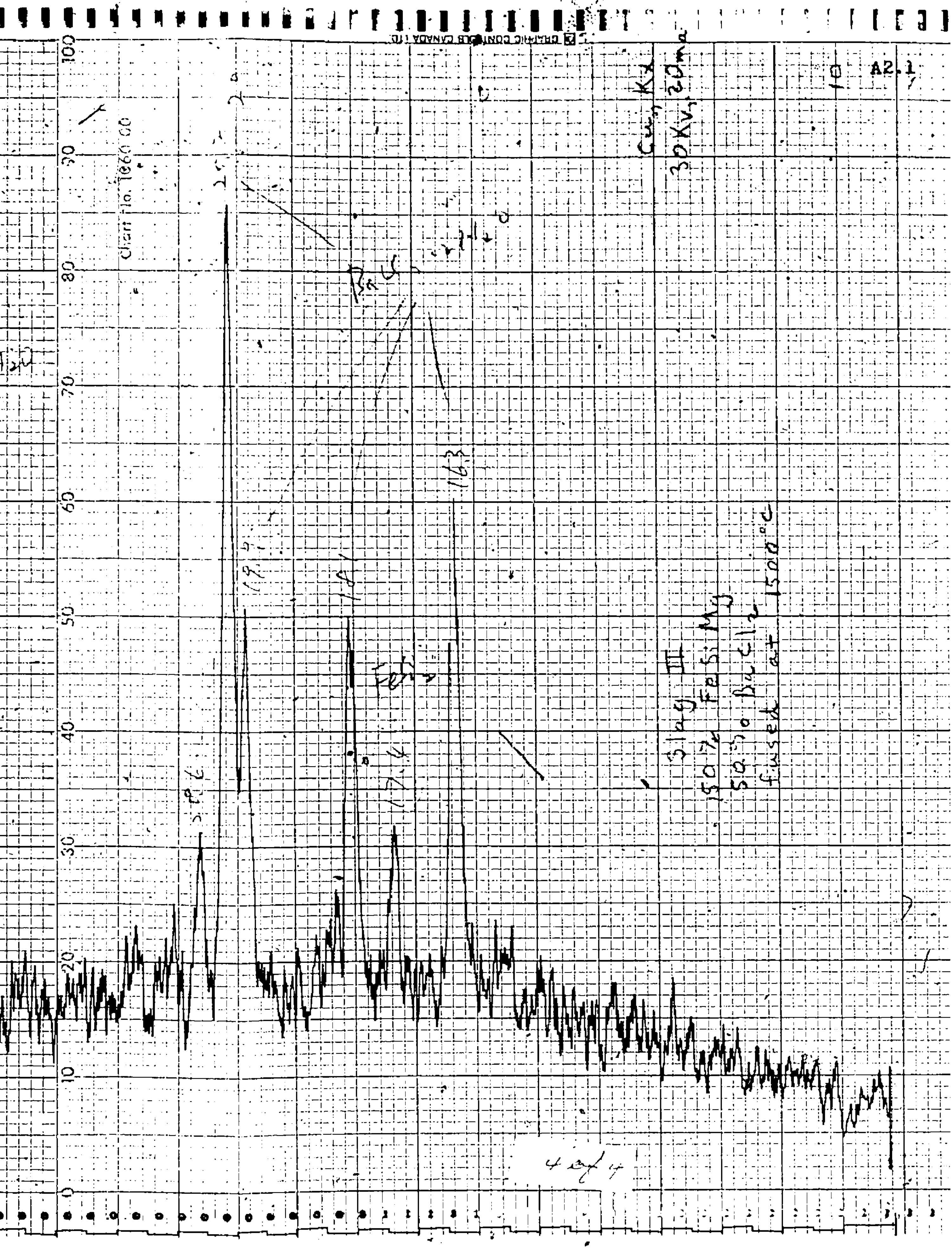

100
90
80
70
60
50
40
30
20
10
0

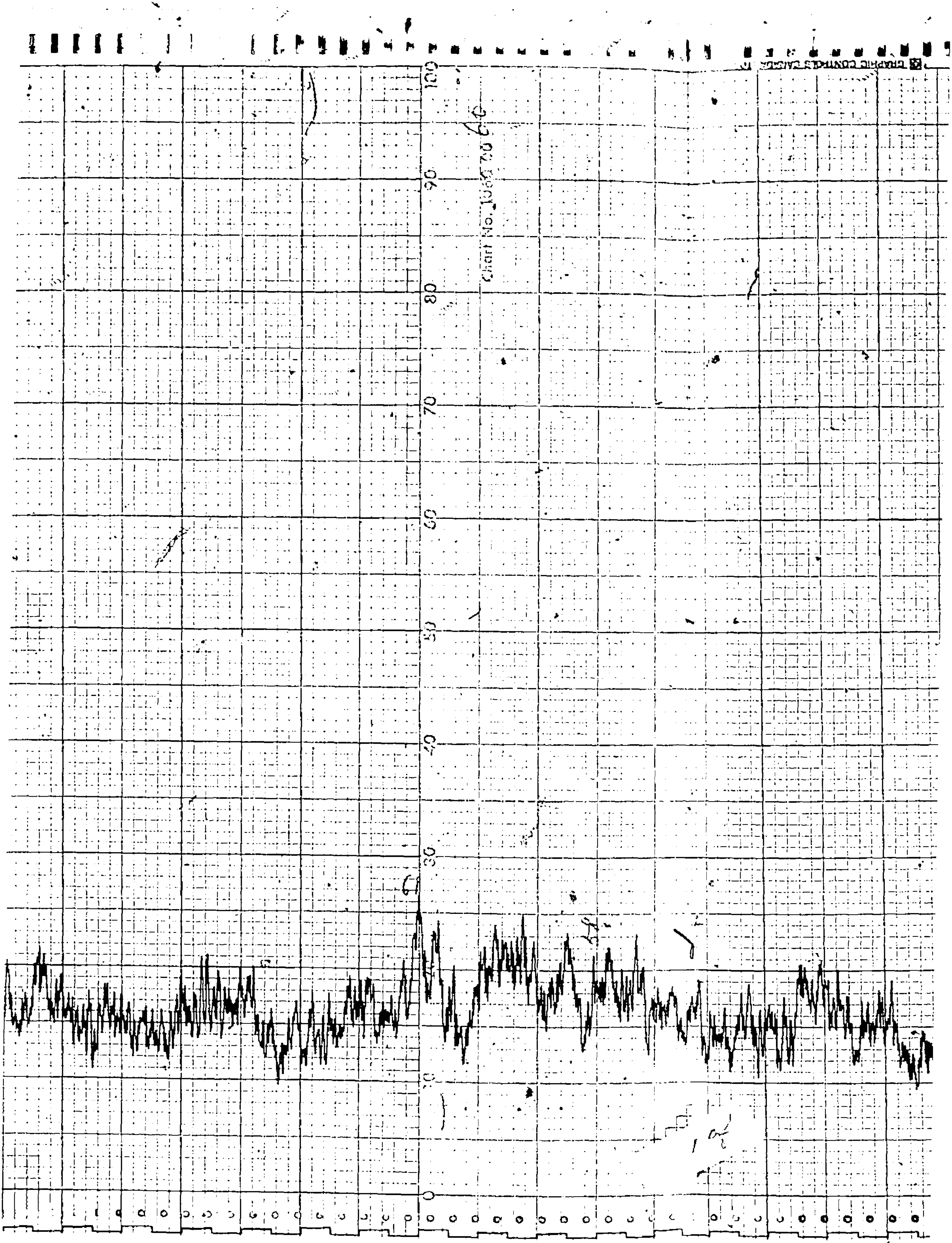




BaCl2 24hr
BaCl




A2.1
Cu, Kα
30Kv, 20ma
Slag III
50% FeSi Mg
50% BaCl2
fused at 1500°C
4 of 4


100
90
Chart No.
80
70
60
50
40
30
0

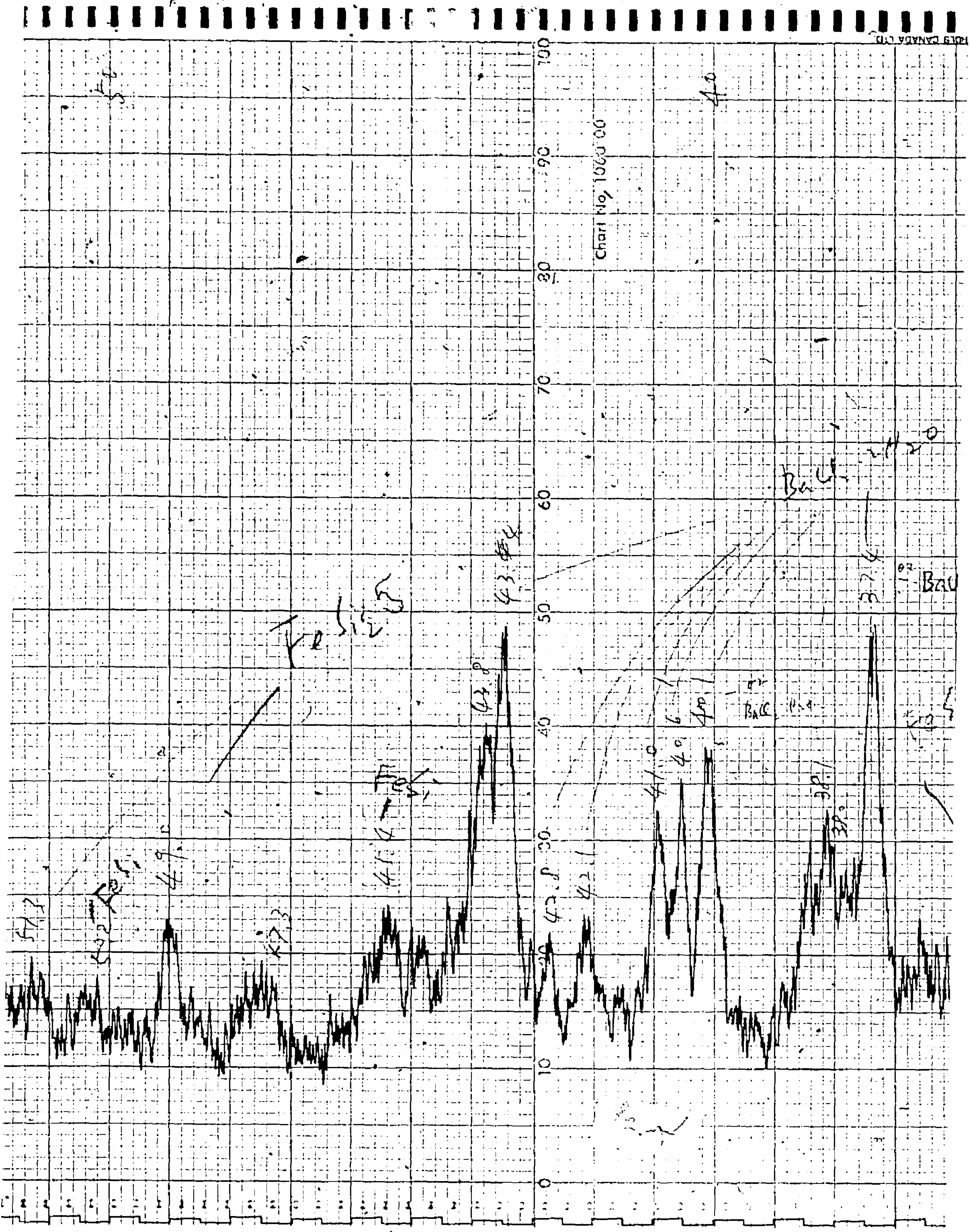


Chart No. 1060 00
100
90
80
70
60
50
40
30
20
10
0

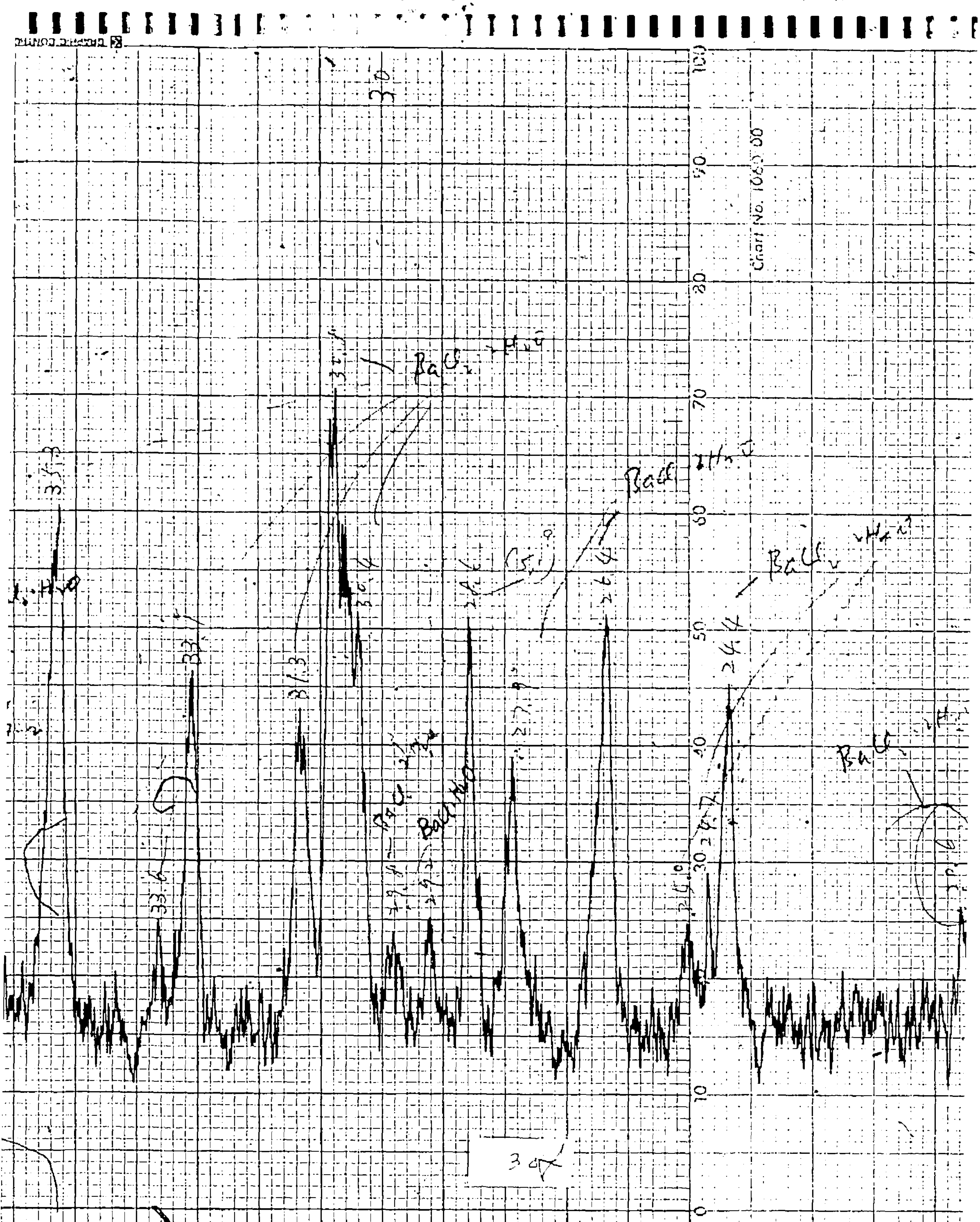
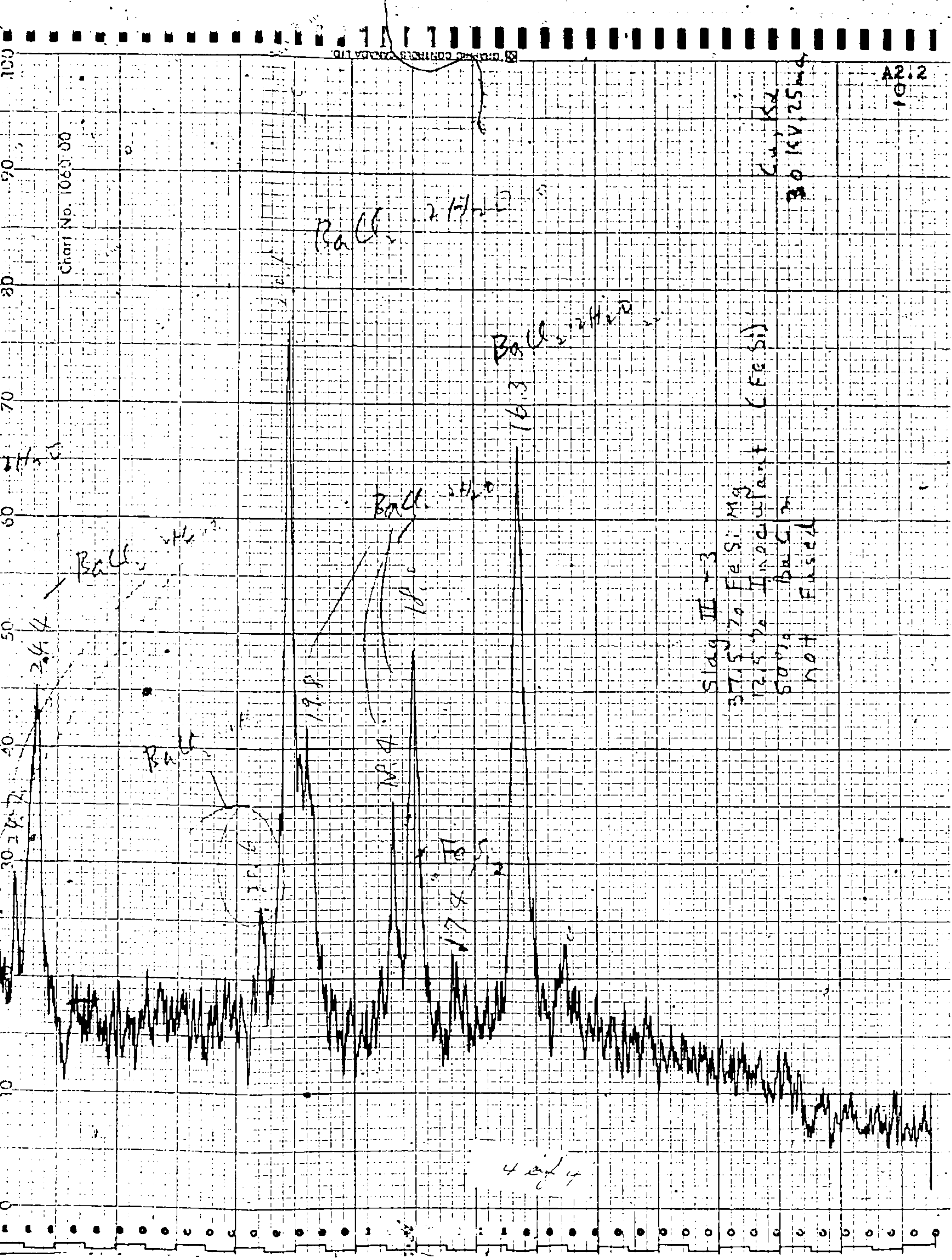
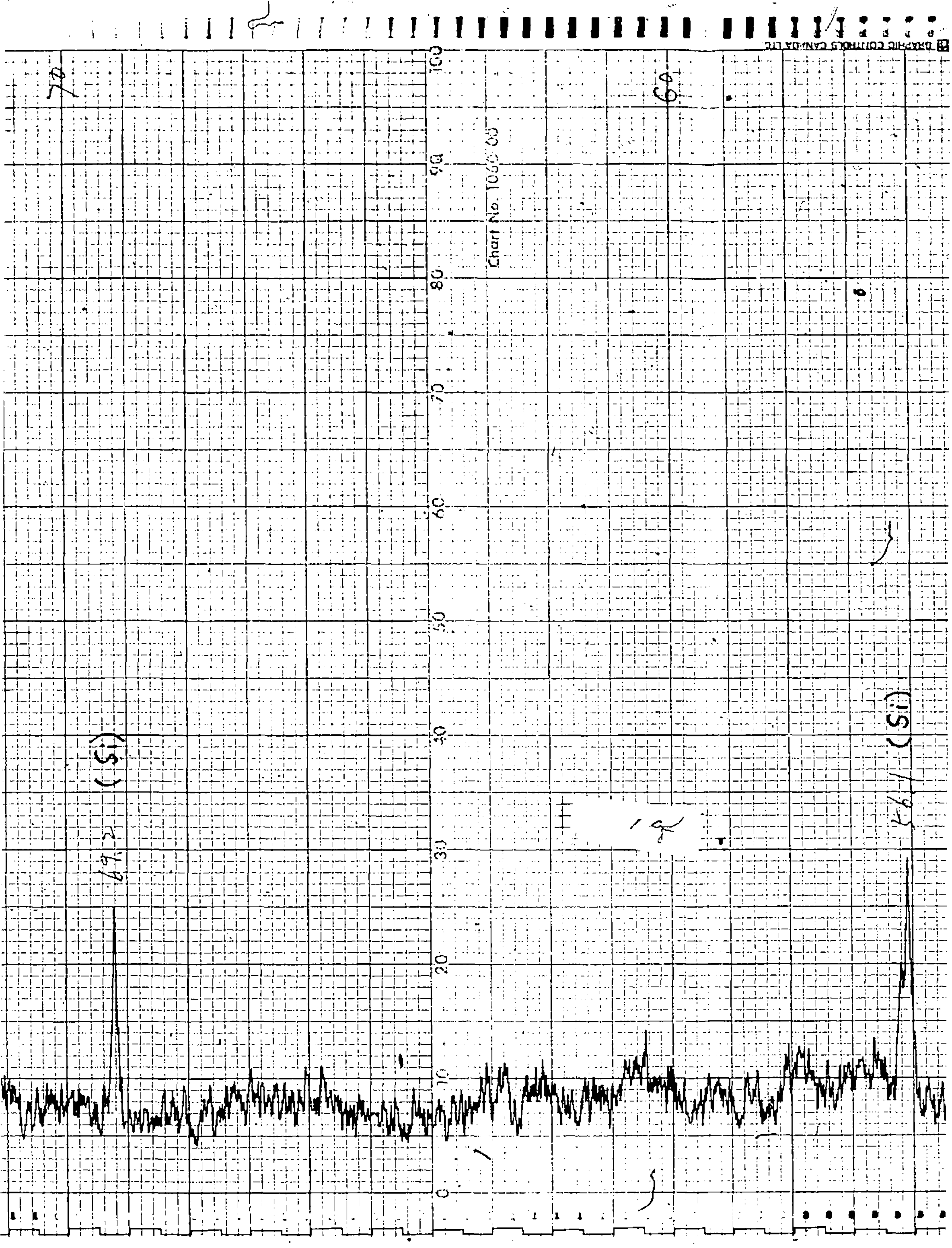
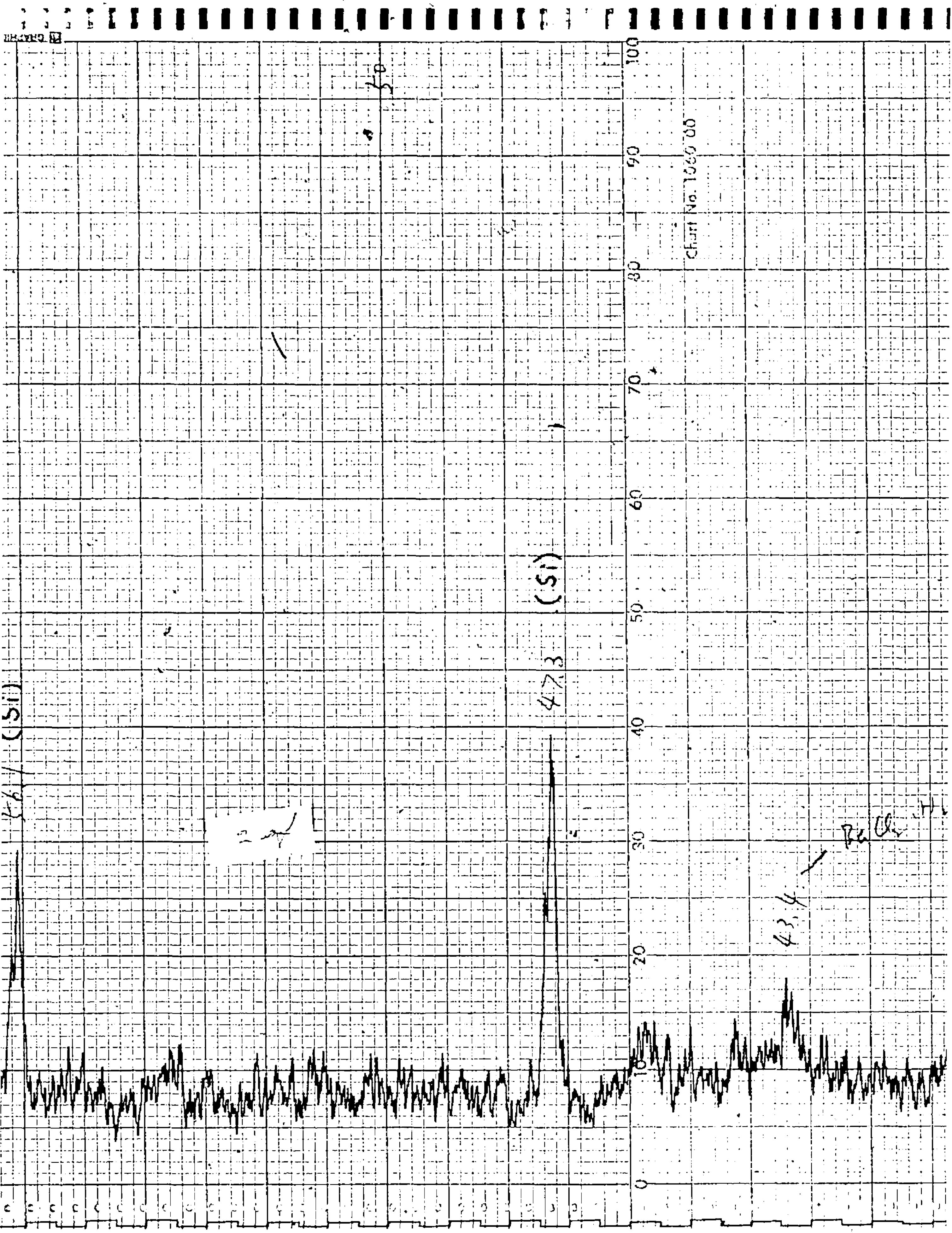
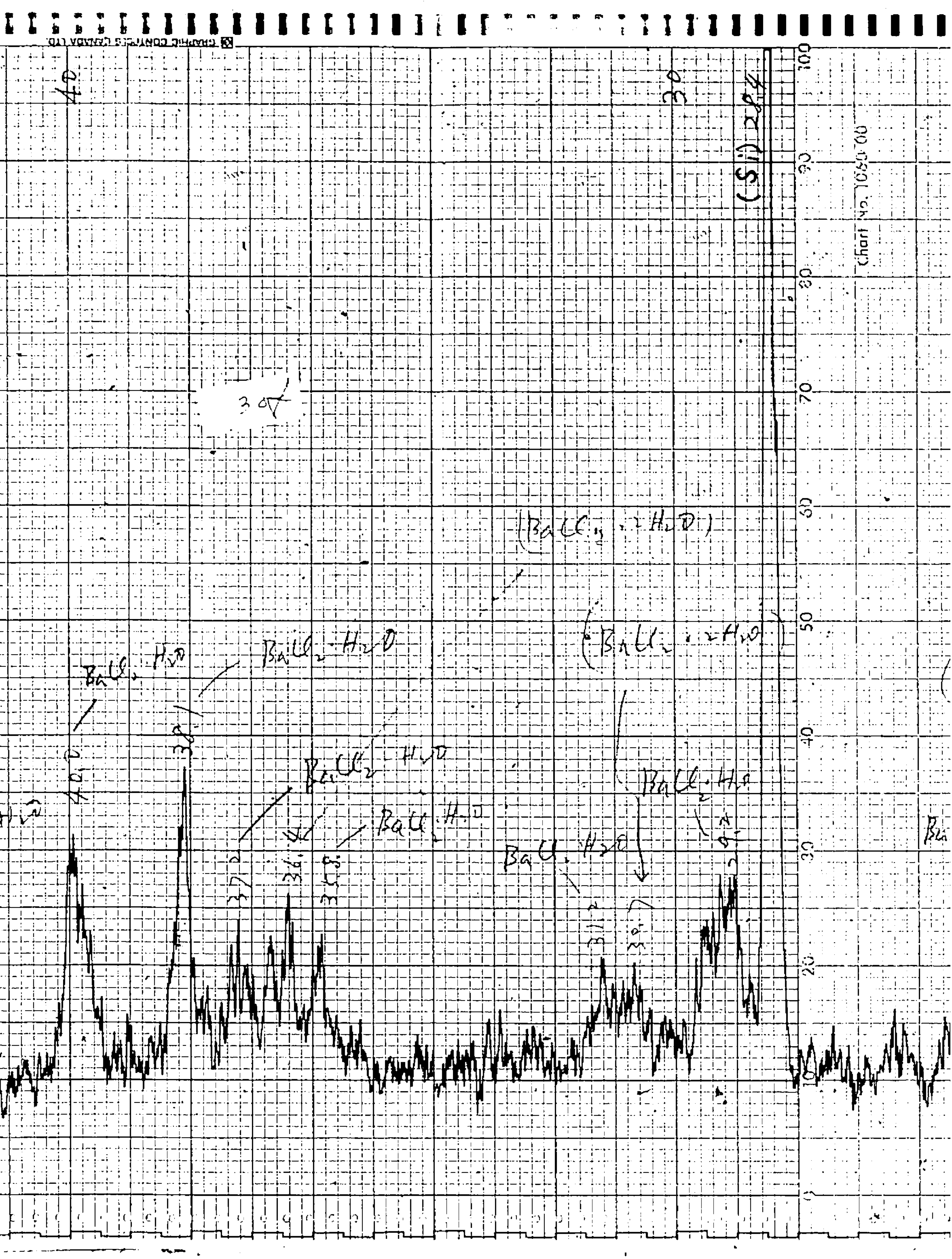


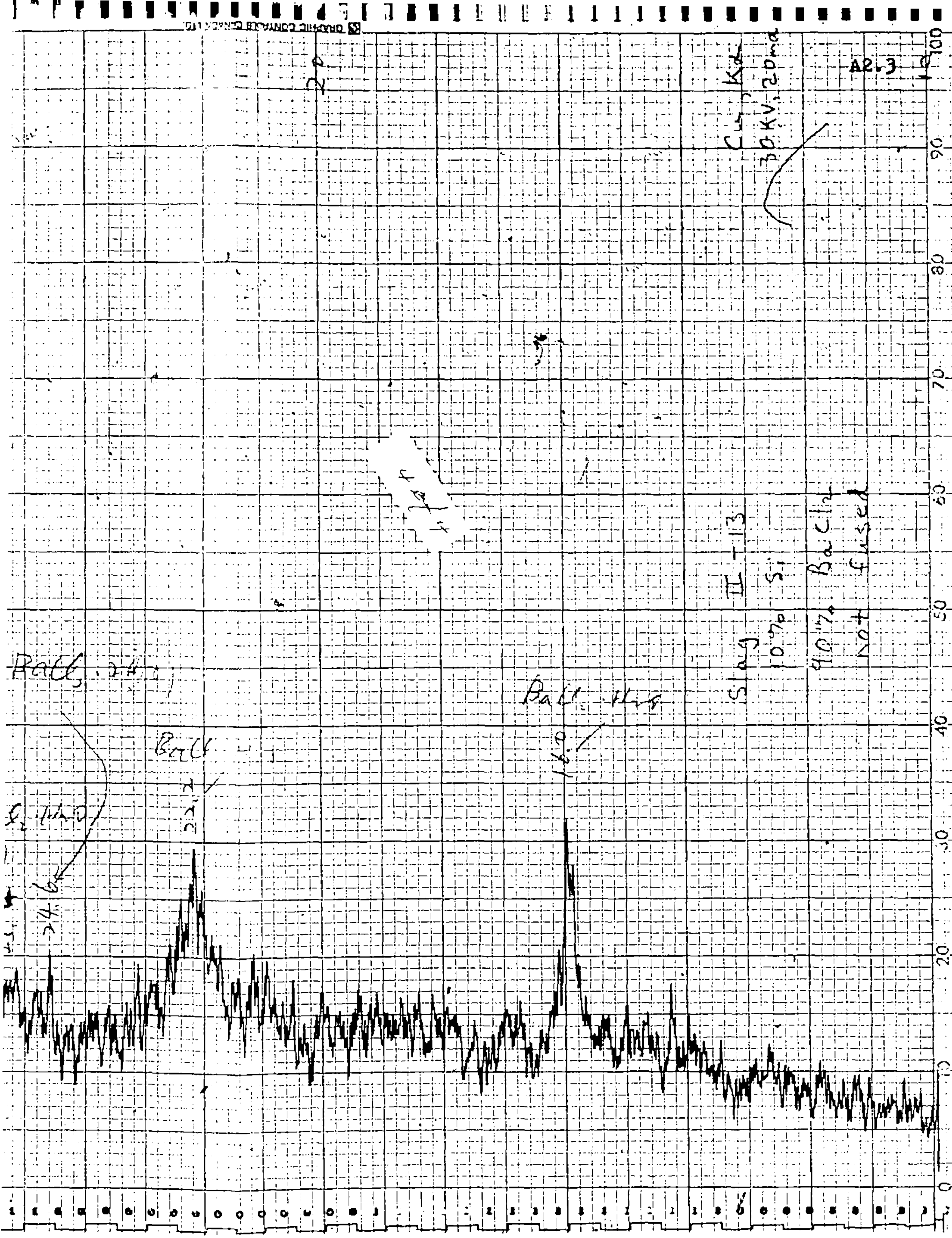
Chart No.
100
90
80
70
60
50
40
30
10
0

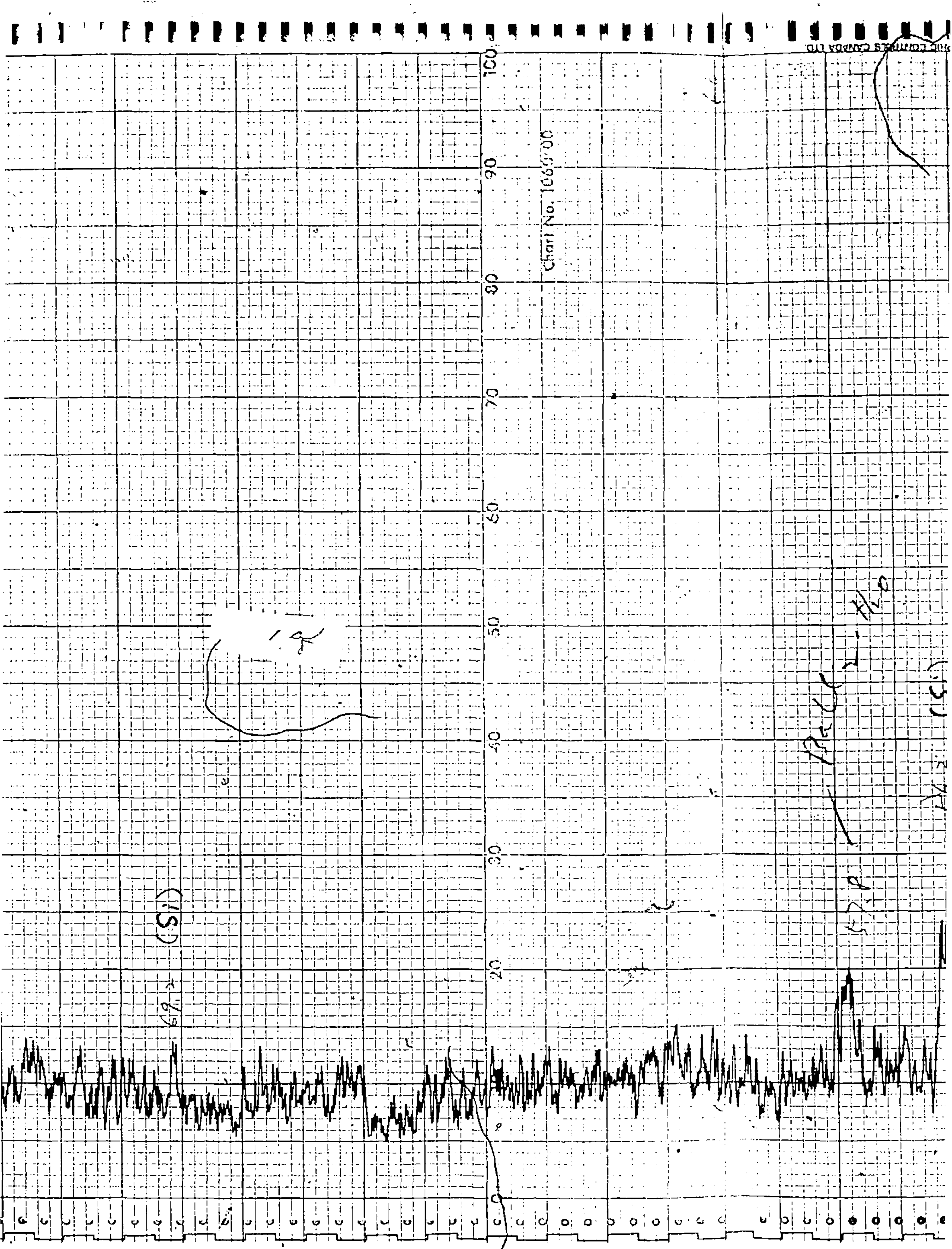

A2.2
Cu, Kα
30 KV, 25 mA
BaCl₂·2H₂O
Slag III-3
37.5% FeSi Mg
12.5% Inoculant (FeSi)
50% BaCl₂
not fused
24.4
19.8
18.4
16.3
4 of 4

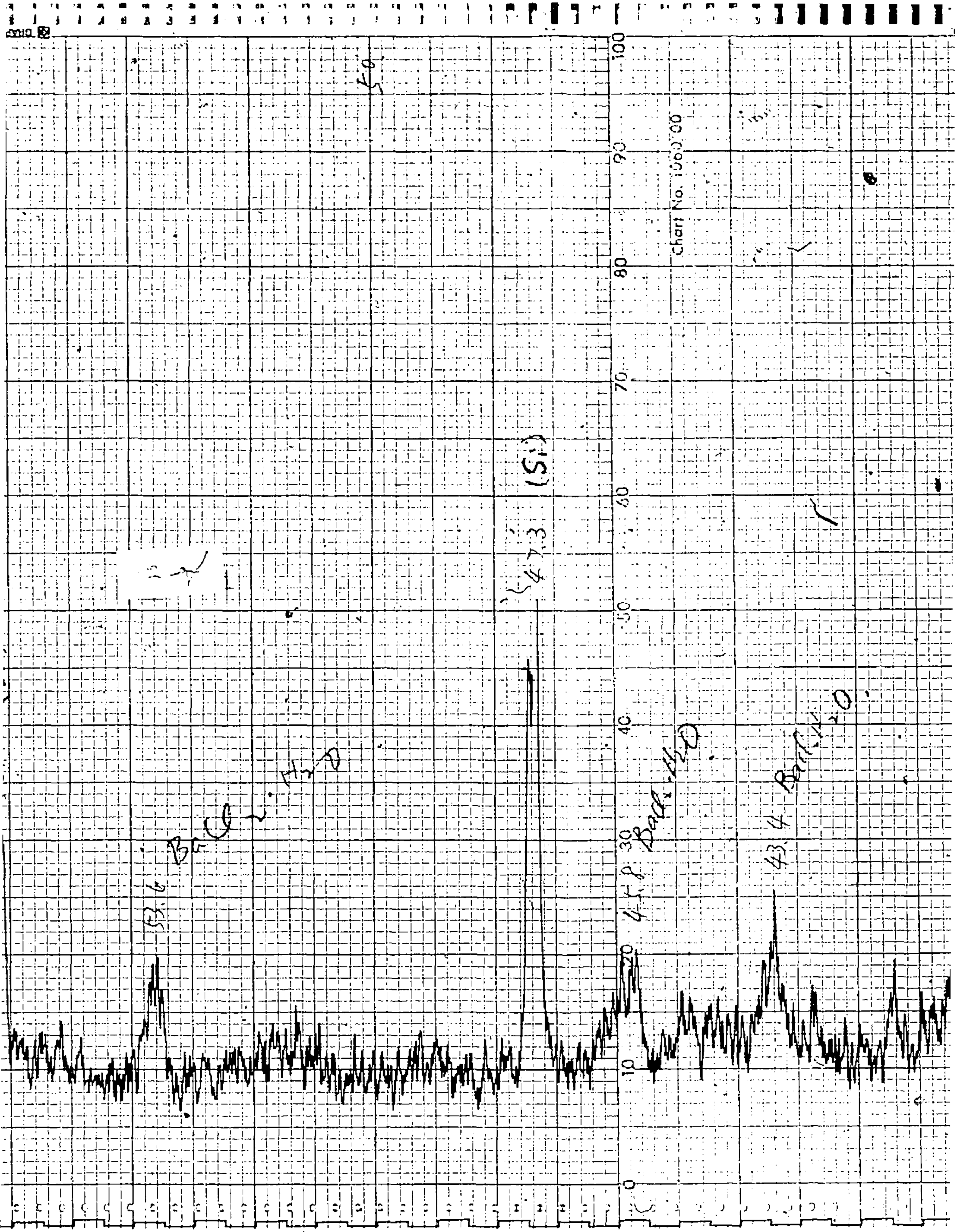

(Si)
(Si)

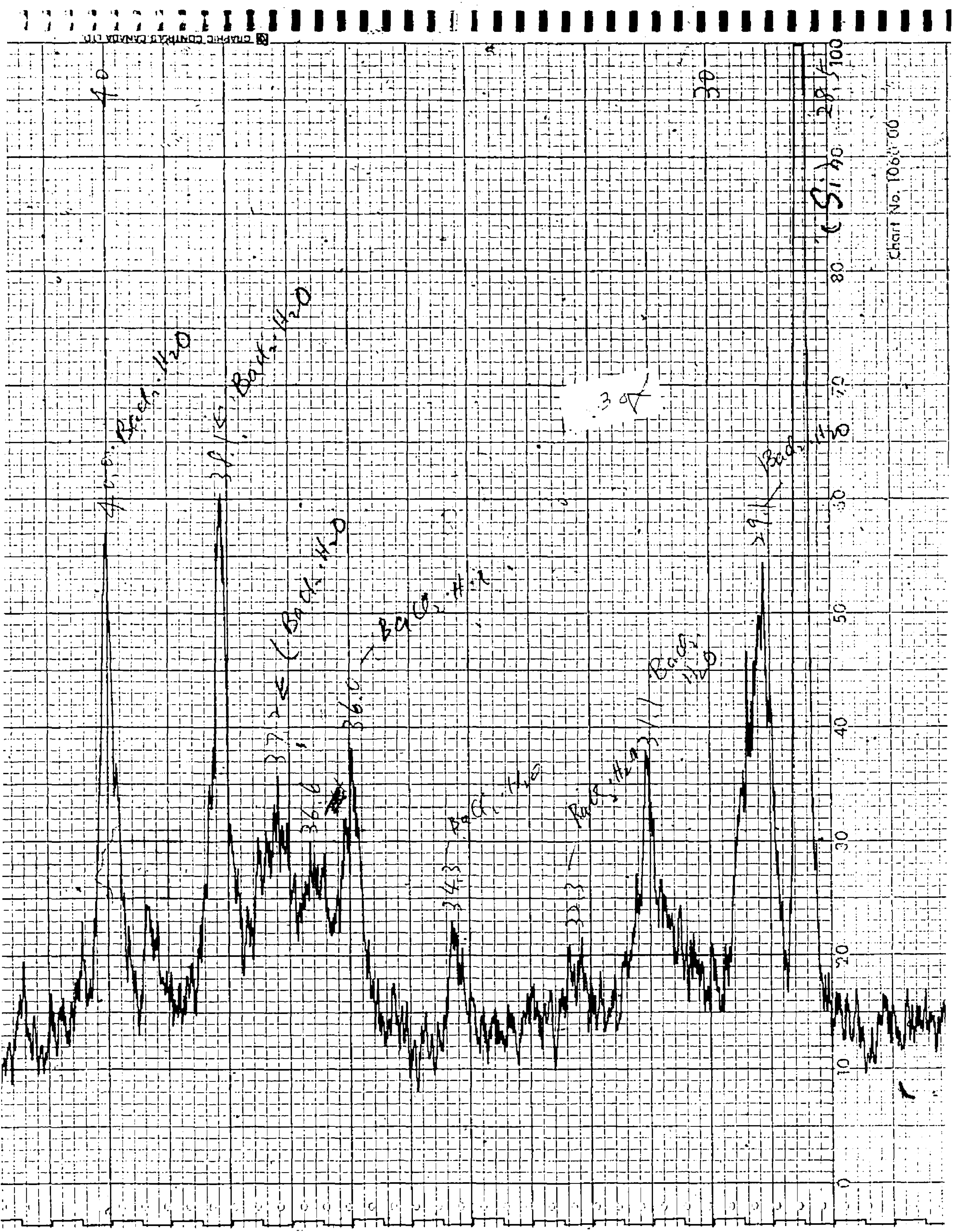

47.3 (Si)
43.4

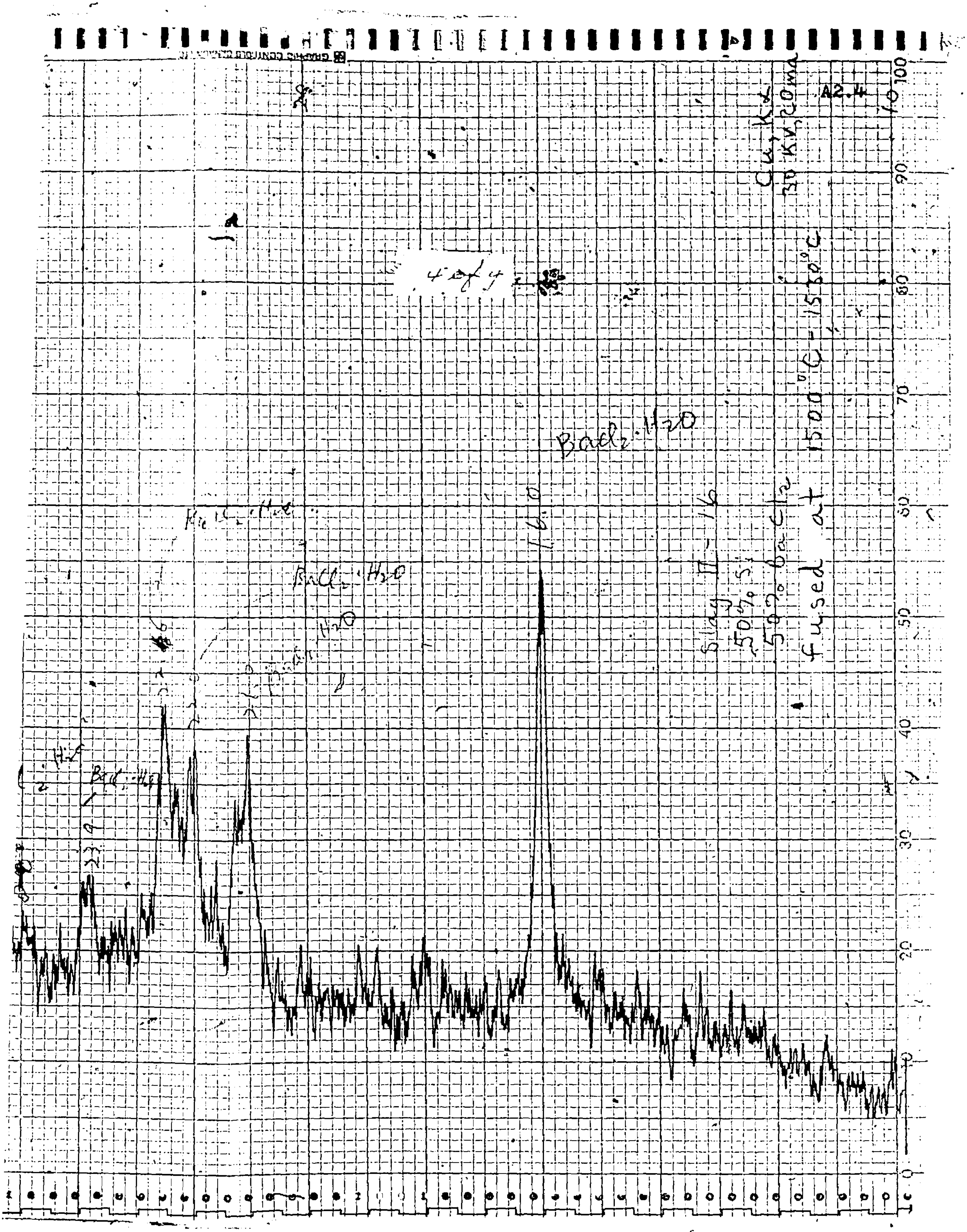

(Si) 28.4
$BaCl_2 \cdot H_2O$
$BaCl_2 \cdot H_2O$
$BaCl_2 \cdot H_2O$
$BaCl_2 \cdot H_2O$
$BaCl_2 \cdot H_2O$
$BaCl_2 \cdot H_2O$
$(BaCl_2 \cdot 2H_2O)$
$(BaCl_2 \cdot 2H_2O)$
100
90
80
70
60
50
40
30
20
10
0

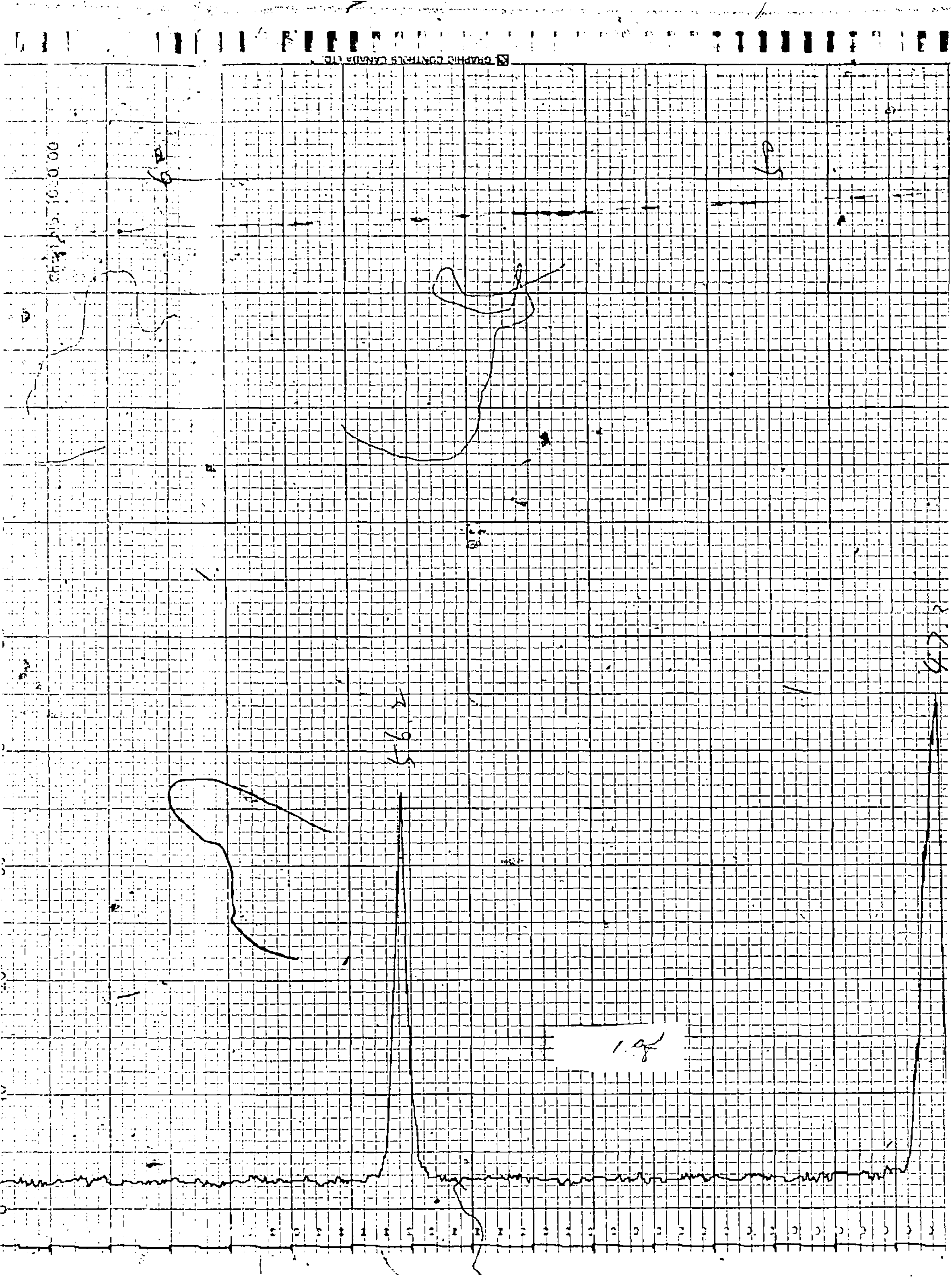

A2.3
Cu, Kα
30 KV, 20 ma
Slag II-13
10% Si
40% BaCl2
Not fused

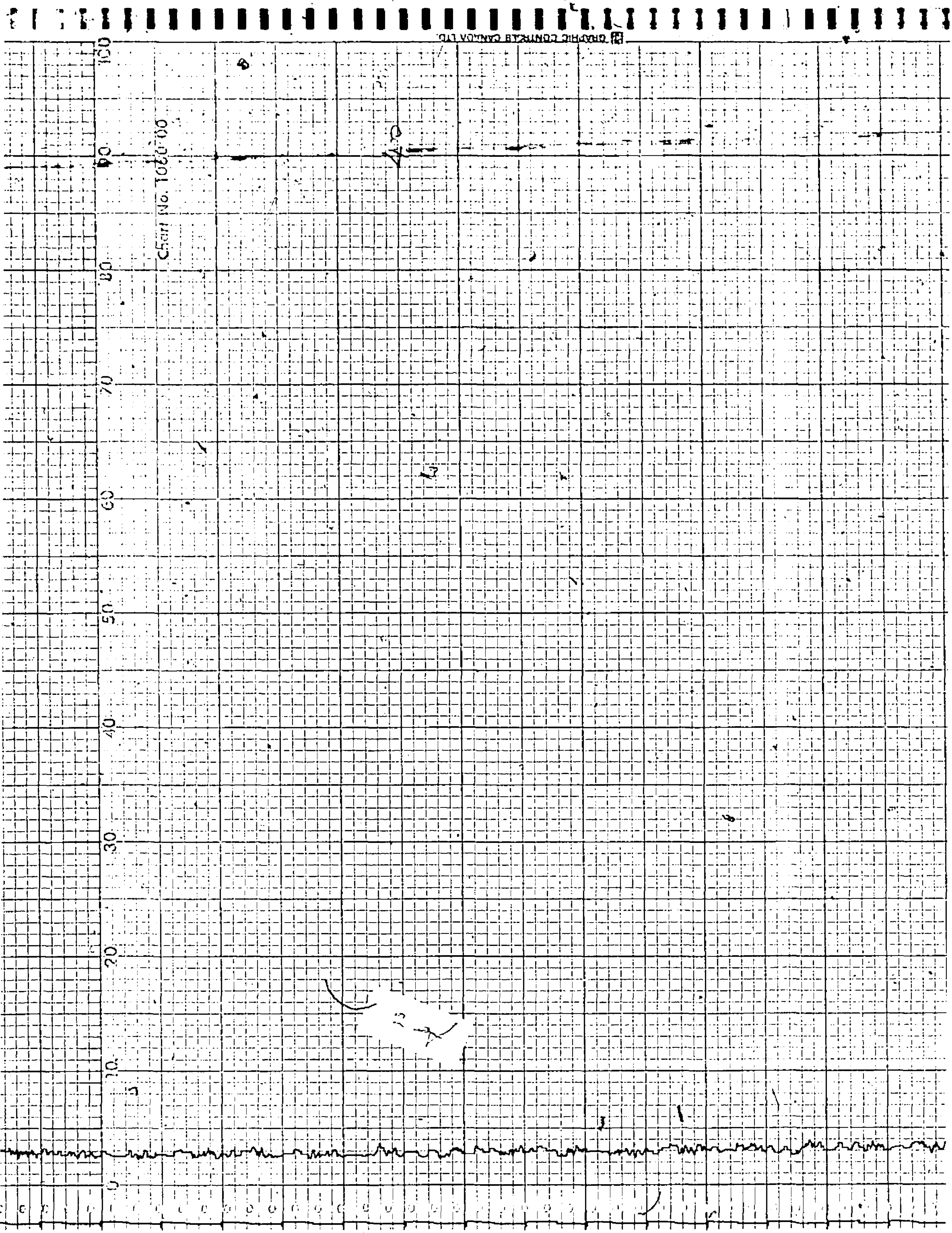

100
90
80
70
60
50
40
30
20
0

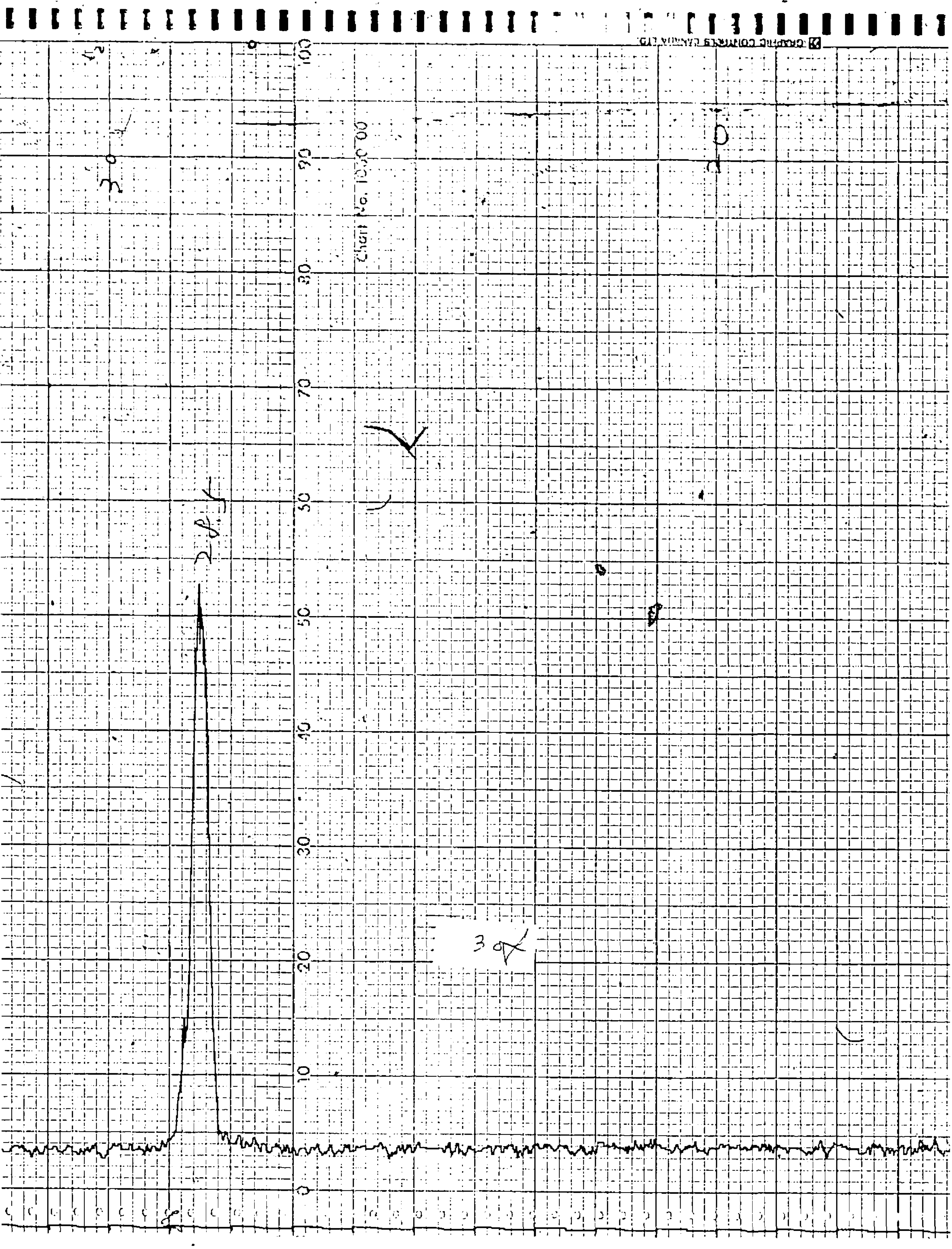

100
90
80
70
60
50
40
30
20
10
0
(Si)

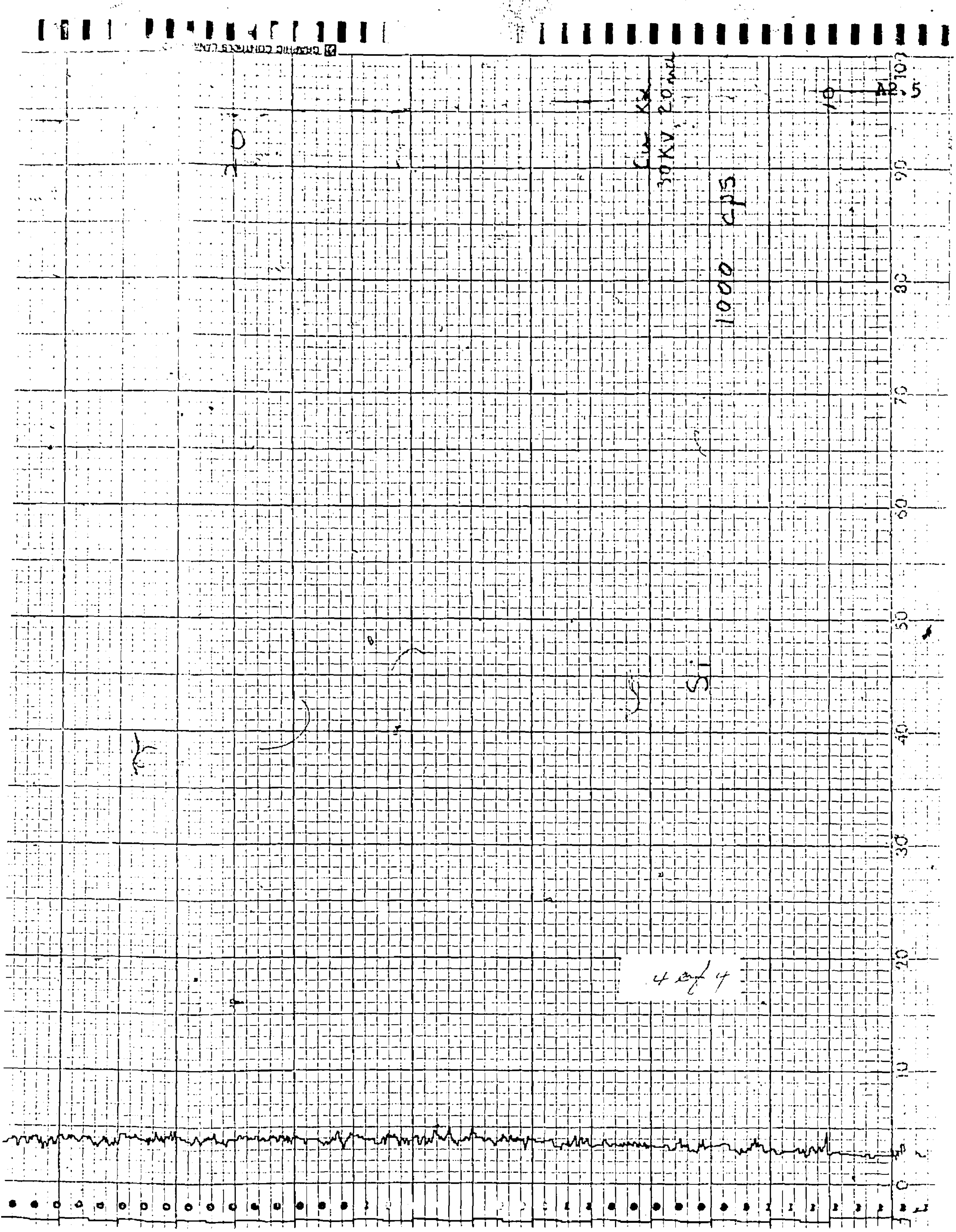



A2.4
Cu Kα
30 KV, 20 mA
4 of 4
$BaCl_2 \cdot H_2O$
Slag II-16
50% Si
50% $BaCl_2$
Fused at 1500°C-1530°C
100
90
80
70
60
50
40
30
20
10
0




100
90
80
70
60
50
40
30
20
10
0




GRAPHIC CONTROLS CORP.
Cu Kα
30 KV, 20 mA
1000 cps
Si
4 of 4
A2.5
100
90
80
70
60
50
40
30
20
10
0

APPENDIX 3. The Results of Image Analyses

SAMPLE ID: A-1-0 20/10/77

DATA COLLECTION FOR 979 PARTICLES

MAX. DIAM. = 61.200 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 195.800 STAND. DEV. = 19.383

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.92	6.72	0.55	0.263	20.02	8.27

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	3	0.31	[
6.30	40	4.09	[**
10.00	148	15.12	[********
16.00	365	37.28	[*******************
25.00	315	32.18	[****************
40.00	104	10.62	[*****
63.00	4	0.41	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	30	3.06	[**
0.100	75	7.66	[****
0.150	52	5.31	[***
0.200	29	2.96	[*
0.250	14	1.43	[*
0.300	17	1.74	[*
0.350	17	1.74	[*
0.400	16	1.63	[*
0.450	39	3.98	[**
0.500	17	1.74	[*
0.550	47	4.80	[**
0.600	75	7.66	[****
0.650	56	5.72	[***
0.700	104	10.62	[*****
0.750	132	13.48	[*******
0.800	133	13.59	[*******
0.850	63	6.44	[***
0.900	56	5.72	[***
0.950	7	0.72	[

SAMPLE ID: A-1-1 6/10/77

DATA COLLECTION FOR 928 PARTICLES

MAX. DIAM. = 101.823 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 185.600 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.04	7.02	0.52	0.259	19.53	9.94

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
1.60	0	0.00	[
2.50	1	0.11	[
4.00	8	0.86	[
6.30	44	4.74	[**
10.00	146	15.73	[********
16.00	392	42.24	[**********************
25.00	276	29.74	[***************
40.00	55	5.93	[***
63.00	5	0.54	[
100.00	1	0.11	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	23	2.48	[*
0.100	76	8.19	[****
0.150	65	7.00	[****
0.200	28	3.02	[**
0.250	20	2.16	[*
0.300	23	2.48	[*
0.350	21	2.26	[*
0.400	24	2.59	[*
0.450	34	3.66	[**
0.500	21	2.26	[*
0.550	62	6.68	[***
0.600	90	9.70	[*****
0.650	64	6.90	[***
0.700	95	10.24	[*****
0.750	91	9.81	[*****
0.800	93	10.02	[*****
0.850	64	6.90	[***
0.900	29	3.13	[**
0.950	5	0.54	[

SAMPLE ID: A-1-2 6/10/77

DATA COLLECTION FOR 715 PARTICLES

MAX. DIAM. = 100.623 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 143.000 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	14.31	8.66	0.38	0.219	21.26	12.33

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	20	2.80	[*
6.30	79	11.05	[******
10.00	172	24.06	[**************
16.00	218	30.49	[******************
25.00	131	18.32	[***********
40.00	85	11.89	[******
63.00	10	1.40	[*

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	26	3.64	[**
0.100	72	10.07	[*****
0.150	58	8.11	[****
0.200	27	3.78	[**
0.250	46	6.43	[***
0.300	66	9.23	[*****
0.350	32	4.48	[**
0.400	58	8.11	[****
0.450	65	9.09	[*****
0.500	27	3.78	[**
0.550	48	6.71	[***
0.600	67	9.37	[*****
0.650	30	4.20	[**
0.700	29	4.06	[**
0.750	36	5.03	[***
0.800	18	2.52	[*
0.850	7	0.98	[
0.900	3	0.42	[

SAMPLE ID: A-1-3 6/10/77

DATA COLLECTION FOR 486 PARTICLES

MAX. DIAM. = 72.000 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 97.200 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	10.67	6.47	0.24	0.160	20.06	12.47

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
1.60	0	0.00	[
2.50	3	0.62	[
4.00	45	9.26	[*****
6.30	102	20.99	[**********
10.00	119	24.49	[************
16.00	129	26.54	[*************
25.00	72	14.81	[*******
40.00	14	2.88	[*
63.00	2	0.41	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	28	5.76	[***
0.100	75	15.43	[********
0.150	70	14.40	[*******
0.200	58	11.93	[******
0.250	57	11.73	[******
0.300	55	11.32	[******
0.350	37	7.61	[****
0.400	23	4.73	[**
0.450	29	5.97	[***
0.500	10	2.06	[*
0.550	22	4.53	[**
0.600	8	1.65	[*
0.650	1	0.21	[
0.700	5	1.03	[*
0.750	8	1.65	[*

SAMPLE ID: A-2-0 11/10/77

DATA COLLECTION FOR 1102 PARTICLES

MAX. DIAM. = 96.598 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 220.400 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	SIGMA (UM)	MIN/MAX MEAN	SIGMA	MAXIMUM DIAMETER MEAN (UM)	SIGMA (UM)
	ALL TYPES	14.55	6.35	0.48	0.266	19.50	9.36

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	10	0.91	[
6.30	55	4.99	[**
10.00	212	19.24	[**********
16.00	439	39.84	[********************
25.00	304	27.59	[**************
40.00	78	7.08	[****
63.00	4	0.36	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	36	3.27	[**
0.100	106	9.62	[*****
0.150	101	9.17	[*****
0.200	44	3.99	[**
0.250	27	2.45	[*
0.300	27	2.45	[*
0.350	18	1.63	[*
0.400	31	2.81	[*
0.450	40	3.63	[**
0.500	31	2.81	[*
0.550	86	7.80	[****
0.600	86	7.80	[****
0.650	73	6.62	[***
0.700	109	9.89	[*****
0.750	107	9.71	[*****
0.800	100	9.07	[*****
0.850	48	4.36	[**
0.900	26	2.36	[*
0.950	6	0.54	[

SAMPLE ID: A-2-1 7/10/77

DATA COLLECTION FOR 763 PARTICLES

MAX. DIAM. = 132.823 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 152.600 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.90	6.91	0.45	0.265	21.44	10.95

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	3	0.39	[
6.30	19	2.49	[*
10.00	101	13.24	[*******
16.00	335	43.91	[**********************
25.00	238	31.19	[****************
40.00	61	7.99	[****
63.00	6	0.79	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	22	2.88	[*
0.100	86	11.27	[******
0.150	69	9.04	[*****
0.200	32	4.19	[**
0.250	24	3.15	[**
0.300	26	3.41	[**
0.350	15	1.97	[*
0.400	26	3.41	[**
0.450	40	5.24	[***
0.500	30	3.93	[**
0.550	52	6.82	[***
0.600	62	8.13	[****
0.650	55	7.21	[****
0.700	47	6.16	[***
0.750	55	7.21	[****
0.800	69	9.04	[*****
0.850	31	4.06	[**
0.900	19	2.49	[*
0.950	3	0.39	[

SAMPLE ID: A-2-2 6/10/77

DATA COLLECTION FOR 685 PARTICLES

MAX. DIAM. = 68.400 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 137.000 STAND. DEV. = 83.905

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	13.26	5.98	0.43	0.247	18.81	9.08

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	10	1.46	[*
6.30	51	7.45	[****
10.00	184	26.86	[*************
16.00	237	34.60	[*****************
25.00	178	25.99	[*************
40.00	23	3.36	[**
63.00	2	0.29	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	16	2.34	[*
0.100	67	9.78	[*****
0.150	51	7.45	[****
0.200	41	5.99	[***
0.250	26	3.80	[**
0.300	35	5.11	[***
0.350	34	4.96	[**
0.400	35	5.11	[***
0.450	37	5.40	[***
0.500	19	2.77	[*
0.550	46	6.72	[***
0.600	65	9.49	[*****
0.650	28	4.09	[**
0.700	64	9.34	[*****
0.750	54	7.88	[****
0.800	45	6.57	[***
0.850	15	2.19	[*
0.900	7	1.02	[*

SAMPLE ID: A-2-4 11/10/77

DATA COLLECTION FOR 819 PARTICLES

MAX. DIAM. = 163.009 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 163.800 STAND. DEV. = 12.194

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
ALL TYPES		17.35	10.83	0.34	0.225	26.98	17.70

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	5	0.61	[
6.30	63	7.69	[****
10.00	140	17.09	[**********
16.00	250	30.53	[***************
25.00	211	25.76	[*************
40.00	116	14.16	[*******
63.00	30	3.66	[**
100.00	4	0.49	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	70	8.55	[****
0.100	96	11.72	[******
0.150	63	7.69	[****
0.200	55	6.72	[***
0.250	51	6.23	[***
0.300	60	7.33	[****
0.350	42	5.13	[***
0.400	58	7.08	[****
0.450	50	6.11	[***
0.500	45	5.49	[***
0.550	51	6.23	[***
0.600	41	5.01	[***
0.650	47	5.74	[***
0.700	31	3.79	[**
0.750	27	3.30	[**
0.800	24	2.93	[*
0.850	7	0.85	[
0.900	1	0.12	[

SAMPLE ID: A-3-0 7/10/77

DATA COLLECTION FOR 1561 PARTICLES

MAX. DIAM. = 52.324 UM MIN. DIAM. = 0.000 UM

PARTICLES/FRAME: MEAN= 312.200 STAND. DEV. = 83.005

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	12.48	4.38	0.51	0.235	16.50	6.17

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	10	0.64	[
6.30	86	5.51	[***
10.00	372	23.83	[************
16.00	769	49.26	[*************************
25.00	318	20.37	[**********
40.00	6	0.38	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	15	0.96	[
0.100	97	6.21	[***
0.150	103	6.60	[***
0.200	59	3.78	[**
0.250	38	2.43	[*
0.300	38	2.43	[*
0.350	36	2.31	[*
0.400	52	3.33	[**
0.450	87	5.57	[***
0.500	59	3.78	[**
0.550	114	7.30	[****
0.600	174	11.15	[******
0.650	106	6.79	[***
0.700	173	11.08	[******
0.750	190	12.17	[******
0.800	130	8.33	[****
0.850	62	3.97	[**
0.900	26	1.67	[*
0.950	2	0.13	[

SAMPLE ID: A-3-1 17/10/77

DATA COLLECTION FOR 884 PARTICLES

MAX. DIAM. = 62.386 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 176.800 STAND. DEV. = 85.184

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
*	ALL TYPES	15.65	8.01	0.39	0.265	21.65	9.84

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 -----1-----2-----3-----4-----5-----6-----7-----8-----9-----10
2.50	0	0.00	[
4.00	8	0.90	[
6.30	52	5.88	[***
10.00	147	16.63	[*********
16.00	339	38.35	[********************
25.00	230	26.02	[*************
40.00	99	11.20	[******
63.00	9	1.02	[*

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 -----1-----2-----3-----4-----5-----6-----7-----8-----9-----10
0.050	36	4.07	[**
0.100	143	16.18	[********
0.150	119	13.46	[*******
0.200	44	4.98	[**
0.250	29	3.28	[**
0.300	20	2.26	[*
0.350	25	2.83	[*
0.400	32	3.62	[**
0.450	41	4.64	[**
0.500	31	3.51	[**
0.550	47	5.32	[***
0.600	76	8.60	[****
0.650	42	4.75	[**
0.700	54	6.11	[***
0.750	60	6.79	[***
0.800	52	5.88	[***
0.850	25	2.83	[*
0.900	8	0.90	[

SAMPLE ID: A-3-2 7/10/77

DATA COLLECTION FOR 748 PARTICLES

MAX. DIAM. = 76.474 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 149.600 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.85	7.66	0.42	0.254	21.78	9.70

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

```
CLASS          CLASS  0    1    2    3    4    5    6    7    8    9   10
LIMIT    NO.     %    -----0----0----0----0----0----0----0----0----0----0
  2.50     0    0.00 [
  4.00     6    0.80 [
  6.30    46    6.15 [***
 10.00   133   17.78 [*********
 16.00   263   35.16 [******************
 25.00   187   25.00 [*************
 40.00   111   14.84 [*******
 63.00     2    0.27 [
```

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

```
CLASS          CLASS  0    1    2    3    4    5    6    7    8    9   10
LIMIT    NO.     %    -----0----0----0----0----0----0----0----0----0----0
 0.050    33    4.41 [**
 0.100    87   11.63 [******
 0.150    60    8.02 [****
 0.200    41    5.48 [***
 0.250    18    2.41 [*
 0.300    30    4.01 [**
 0.350    29    3.88 [**
 0.400    37    4.95 [**
 0.450    50    6.68 [***
 0.500    33    4.41 [**
 0.550    50    6.68 [***
 0.600    51    6.82 [***
 0.650    41    5.48 [***
 0.700    57    7.62 [****
 0.750    52    6.95 [***
 0.800    46    6.15 [***
 0.850    25    3.34 [**
 0.900     8    1.07 [*
```

SAMPLE ID: A-3-3 17/10/77

DATA COLLECTION FOR 619 PARTICLES

MAX. DIAM. = 70.436 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 123.800 STAND. DEV. = 58.660

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	13.29	6.56	0.44	0.261	17.54	7.50

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	8	1.29	[*
6.30	45	7.27	[****
10.00	149	24.07	[************
16.00	261	42.16	[*********************
25.00	134	21.65	[***********
40.00	16	2.58	[*
63.00	6	0.97	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	13	2.10	[*
0.100	70	11.31	[******
0.150	63	10.18	[*****
0.200	39	6.30	[***
0.250	20	3.23	[**
0.300	23	3.72	[**
0.350	15	2.42	[*
0.400	12	1.94	[*
0.450	37	5.98	[***
0.500	19	3.07	[**
0.550	49	7.92	[****
0.600	42	6.79	[***
0.650	38	6.14	[***
0.700	54	8.72	[****
0.750	47	7.59	[****
0.800	42	6.79	[***
0.850	26	4.20	[**
0.900	8	1.29	[*
0.950	2	0.32	[

SAMPLE ID: A-3-4 20/10/77

DATA COLLECTION FOR 860 PARTICLES

MAX. DIAM. = 77.640 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 172.000 STAND. DEV. = 58.731

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	19.81	7.81	0.45	0.282	26.79	11.09

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10 (-----0-----0-----0-----0-----0-----0-----0-----0-----0-----0)
2.50	0	0.00	[
4.00	3	0.35	[
6.30	19	2.21	[*
10.00	58	6.74	[***
16.00	209	24.30	[************
25.00	377	43.84	[**********************
40.00	183	21.28	[***********
63.00	11	1.28	[*

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10 (-----0-----0-----0-----0-----0-----0-----0-----0-----0-----0)
0.050	57	6.63	[***
0.100	132	15.35	[********
0.150	51	5.93	[***
0.200	18	2.09	[*
0.250	10	1.16	[*
0.300	17	1.98	[*
0.350	28	3.26	[**
0.400	34	3.95	[**
0.450	34	3.95	[**
0.500	29	3.37	[**
0.550	36	4.19	[**
0.600	56	6.51	[***
0.650	59	6.86	[***
0.700	69	8.02	[****
0.750	87	10.12	[*****
0.800	79	9.19	[*****
0.850	47	5.47	[***
0.900	15	1.74	[*
0.950	2	0.23	[

```
SAMPLE ID: A-4-0                                   13/10/77

DATA COLLECTION FOR  1234 PARTICLES

MAX. DIAM. =   68.424 UM    MIN. DIAM. =    0.900 UM

PARTICLES/FRAME:   MEAN=  246.800    STAND. DEV. =    0.000

 PART  CHEMICAL        AVERAGE DIAMETER   MIN/MAX       MAXIMUM DIAMETER
 TYPE   NAME            MEAN    SIGMA    MEAN SIGMA       MEAN    SIGMA
                        (UM)    (UM)                      (UM)    (UM)
       ALL TYPES       12.95     4.60    0.47 0.264      17.34     6.71

            FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION
--------------------------------------------------

CLASS        CLASS  0    1    2    3    4    5    6    7    8    9    10
LIMIT    NO.   %    -----0----0----0----0----0----0----0----0----0----0
  1.60     0  0.00 [
  2.50     2  0.16 [
  4.00    14  1.13 [*
  6.30    70  5.67 [***
 10.00   237 19.21 [**********
 16.00   616 49.92 [*************************
 25.00   284 23.01 [************
 40.00    11  0.89 [

            FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION
--------------------------------------------------

CLASS        CLASS  0    1    2    3    4    5    6    7    8    9    10
LIMIT    NO.   %    -----0----0----0----0----0----0----0----0----0----0
  0.050   21  1.70 [*
  0.100  128 10.37 [*****
  0.150  122  9.89 [*****
  0.200   65  5.27 [***
  0.250   34  2.76 [*
  0.300   34  2.76 [*
  0.350   31  2.51 [*
  0.400   39  3.16 [**
  0.450   45  3.65 [**
  0.500   19  1.54 [*
  0.550   66  5.35 [***
  0.600  100  8.10 [****
  0.650   97  7.86 [****
  0.700  131 10.62 [*****
  0.750  120  9.72 [*****
  0.800  111  9.00 [****
  0.850   49  3.97 [**
  0.900   20  1.62 [*
  0.950    2  0.16 [
```

SAMPLE ID: A-4-1 7/10/77

DATA COLLECTION FOR 1222 PARTICLES

MAX. DIAM. = 108.187 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 244.400 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	13.22	6.30	0.42	0.256	18.69	7.88

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	22	1.80	[*
6.30	100	8.18	[****
10.00	282	23.08	[************
16.00	531	43.45	[**********************
25.00	205	16.78	[********
40.00	81	6.63	[***
63.00	0	0.00	[
100.00	1	0.08	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	25	2.05	[*
0.100	140	11.46	[******
0.150	119	9.74	[*****
0.200	72	5.89	[***
0.250	52	4.26	[**
0.300	65	5.32	[***
0.350	47	3.85	[**
0.400	59	4.83	[**
0.450	68	5.56	[***
0.500	55	4.50	[**
0.550	80	6.55	[***
0.600	70	5.73	[***
0.650	58	4.75	[**
0.700	73	5.97	[***
0.750	97	7.94	[****
0.800	71	5.81	[***
0.850	40	3.27	[**
0.900	29	2.37	[*
0.950	2	0.16	[

SAMPLE ID: A-4-3 7/10/77

DATA COLLECTION FOR 957 PARTICLES

MAX. DIAM. = 128.798 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 191.400 STAND. DEV.= 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	12.41	6.99	0.43	0.231	17.73	11.83

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
1.60	0	0.00	[
2.50	1	0.10	[
4.00	25	2.61	[*
6.30	94	9.82	[*****
10.00	294	30.72	[***************
16.00	337	35.21	[******************
25.00	174	18.18	[*********
40.00	20	2.09	[*
63.00	11	1.15	[*
100.00	1	0.10	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	17	1.78	[*
0.100	65	6.79	[***
0.150	85	8.88	[****
0.200	57	5.96	[***
0.250	36	3.76	[**
0.300	68	7.11	[****
0.350	35	3.66	[**
0.400	61	6.37	[***
0.450	65	6.79	[***
0.500	34	3.55	[**
0.550	75	7.84	[****
0.600	108	11.29	[******
0.650	38	3.97	[**
0.700	75	7.84	[****
0.750	67	7.00	[****
0.800	42	4.39	[**
0.850	20	2.09	[*
0.900	7	0.73	[
0.950	2	0.21	[

SAMPLE ID: A-4-5 7/10/77

DATA COLLECTION FOR 589 PARTICLES

MAX. DIAM. = 121.500 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 117.800 STAND. DEV. = 21.183

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	13.08	6.71	0.42	0.249	18.06	9.34

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
			-----0----0----0----0----0----0----0----0----0----0
2.50	0	0.00	[
4.00	11	1.87	[*
6.30	50	8.49	[****
10.00	146	24.79	[************
16.00	210	35.65	[******************
25.00	161	27.33	[**************
40.00	9	1.53	[*
63.00	1	0.17	[
100.00	0	0.00	[
160.00	1	0.17	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
			-----0----0----0----0----0----0----0----0----0----0
0.050	16	2.72	[*
0.100	59	10.02	[*****
0.150	57	9.68	[*****
0.200	41	6.96	[***
0.250	24	4.07	[**
0.300	31	5.26	[***
0.350	19	3.23	[**
0.400	27	4.58	[**
0.450	35	5.94	[***
0.500	15	2.55	[*
0.550	34	5.77	[***
0.600	45	7.64	[****
0.650	34	5.77	[***
0.700	61	10.36	[*****
0.750	43	7.30	[****
0.800	30	5.09	[***
0.850	13	2.21	[*
0.900	4	0.68	[
0.950	1	0.17	[

SAMPLE ID: YY-3 6/10/77

DATA COLLECTION FOR 817 PARTICLES

MAX. DIAM. = 78.486 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 163.400 STAND. DEV. = 45.153

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.60	7.38	0.54	0.238	19.80	9.11

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

```
CLASS          CLASS  0    1    2    3    4    5    6    7    8    9    10
LIMIT     NO.    %    -----0----0----0----0----0----0----0----0----0----0
  2.50      0   0.00 [
  4.00      4   0.49 [
  6.30     43   5.26 [***
 10.00    133  16.28 [********
 16.00    310  37.94 [*******************
 25.00    242  29.62 [***************
 40.00     78   9.55 [*****
 63.00      7   0.86 [
```

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

```
CLASS          CLASS  0    1    2    3    4    5    6    7    8    9    10
LIMIT     NO.    %    -----0----0----0----0----0----0----0----0----0----0
 0.050     13   1.59 [*
 0.100     67   8.20 [****
 0.150     29   3.55 [**
 0.200     20   2.45 [*
 0.250     17   2.08 [*
 0.300      9   1.10 [*
 0.350     12   1.47 [*
 0.400     25   3.06 [**
 0.450     53   6.49 [***
 0.500     23   2.82 [*
 0.550     55   6.73 [***
 0.600     75   9.18 [*****
 0.650     70   8.57 [****
 0.700     92  11.26 [******
 0.750     97  11.87 [******
 0.800    100  12.24 [******
 0.850     37   4.53 [**
 0.900     23   2.82 [*
```

SAMPLE ID: YY-41 11/10/77

DATA COLLECTION FOR 804 PARTICLES

MAX. DIAM. = 76.474 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 160.800 STAND. DEV. = 8.927

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	SIGMA (UM)	MIN/MAX MEAN	SIGMA	MAXIMUM DIAMETER MEAN (UM)	SIGMA (UM)
	ALL TYPES	15.55	7.01	0.44	0.252	22.06	9.07

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	11	1.37	[*
6.30	45	5.60	[***
10.00	142	17.66	[*********
16.00	267	33.21	[*****************
25.00	249	30.97	[***************
40.00	89	11.07	[******
63.00	1	0.12	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	27	3.36	[**
0.100	79	9.83	[*****
0.150	59	7.34	[****
0.200	40	4.98	[**
0.250	30	3.73	[**
0.300	39	4.85	[**
0.350	43	5.35	[***
0.400	39	4.85	[**
0.450	53	6.59	[***
0.500	33	4.10	[**
0.550	47	5.85	[***
0.600	63	7.84	[****
0.650	40	4.98	[**
0.700	46	5.72	[***
0.750	71	8.83	[****
0.800	50	6.22	[***
0.850	26	3.23	[**
0.900	16	1.99	[*
0.950	3	0.37	[

SAMPLE ID: YY-42 6/10/77

DATA COLLECTION FOR 622 PARTICLES

MAX. DIAM. = 73.822 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 124.400 STAND. DEV. = 62.250

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.51	7.44	0.39	0.253	21.92	9.37

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	12	1.93	[*
6.30	34	5.47	[***
10.00	115	18.49	[**********
16.00	205	32.96	[******************
25.00	179	28.78	[****************
40.00	74	11.90	[*******
63.00	3	0.48	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	30	4.82	[**
0.100	89	14.31	[********
0.150	61	9.81	[*****
0.200	30	4.82	[**
0.250	23	3.70	[**
0.300	23	3.70	[**
0.350	16	2.57	[*
0.400	35	5.63	[***
0.450	39	6.27	[***
0.500	24	3.86	[**
0.550	44	7.07	[****
0.600	48	7.72	[****
0.650	35	5.63	[***
0.700	35	5.63	[***
0.750	42	6.75	[***
0.800	33	5.31	[***
0.850	10	1.61	[*
0.900	4	0.64	[
0.950	1	0.16	[

SAMPLE ID: YY-43 7/10/77

DATA COLLECTION FOR 845 PARTICLES

MAX. DIAM. = 76.474 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 169.000 STAND. DEV. = 59.408

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	16.18	8.44	0.46	0.247	22.17	10.59

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
1.60	0	0.00	[
2.50	1	0.12	[
4.00	15	1.78	[*
6.30	73	8.64	[****
10.00	135	15.98	[********
16.00	259	30.65	[***************
25.00	215	25.44	[*************
40.00	140	16.57	[********
63.00	7	0.83	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	29	3.43	[**
0.100	76	8.99	[****
0.150	38	4.50	[**
0.200	33	3.91	[**
0.250	40	4.73	[**
0.300	42	4.97	[**
0.350	32	3.79	[**
0.400	54	6.39	[***
0.450	49	5.80	[***
0.500	36	4.26	[**
0.550	66	7.81	[****
0.600	59	6.98	[***
0.650	48	5.68	[***
0.700	65	7.69	[****
0.750	78	9.23	[*****
0.800	50	5.92	[***
0.850	28	3.31	[**
0.900	20	2.37	[*
0.950	2	0.24	[

SAMPLE ID: YY-45 17/10/77

DATA COLLECTION FOR 625 PARTICLES

MAX. DIAM. = 76.474 UM MIN. DIAM. = 0.900 UM

.RTICLES/FRAME: MEAN=. 125.000 STAND. DEV. = 60.789

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	18.71	8.49	0.43	0.285	25.59	11.19

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 -1-2-3-4-5-6-7-8-9-10
2.50	0	0.00	[
4.00	6	0.96	[
6.30	26	4.16	[**
10.00	55	8.80	[****
16.00	172	27.52	[**************
25.00	242	38.72	[*******************
40.00	115	18.40	[*********
63.00	9	1.44	[*

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 -1-2-3-4-5-6-7-8-9-10
0.050	43	6.88	[***
0.100	99	15.84	[********
0.150	54	8.64	[****
0.200	13	2.08	[*
0.250	16	2.56	[*
0.300	15	2.40	[*
0.350	12	1.92	[*
0.400	24	3.84	[**
0.450	28	4.48	[**
0.500	18	2.88	[*
0.550	30	4.80	[**
0.600	42	6.72	[***
0.650	37	5.92	[***
0.700	41	6.56	[***
0.750	51	8.16	[****
0.800	59	9.44	[*****
0.850	23	3.68	[**
0.900	19	3.04	[**
0.950	1	0.16	[

SAMPLE ID: YY-46 6/10/77

DATA COLLECTION FOR 517 PARTICLES

MAX. DIAM. = 64.399 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 103.400 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	14.46	6.80	0.47	0.238	19.19	8.07

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	9	1.74	[*
6.30	31	6.00	[***
10.00	93	17.99	[*********
16.00	216	41.78	[*********************
25.00	127	24.56	[************
40.00	39	7.54	[****
63.00	2	0.39	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	6	1.16	[*
0.100	51	9.86	[*****
0.150	31	6.00	[***
0.200	24	4.64	[**
0.250	9	1.74	[*
0.300	14	2.71	[*
0.350	16	3.09	[**
0.400	28	5.42	[***
0.450	39	7.54	[****
0.500	24	4.64	[**
0.550	42	8.12	[****
0.600	43	8.32	[****
0.650	37	7.16	[****
0.700	48	9.28	[*****
0.750	50	9.67	[*****
0.800	36	6.96	[***
0.850	12	2.32	[*
0.900	7	1.35	[*

SAMPLE ID: YY-55 7/10/77

DATA COLLECTION FOR 648 PARTICLES

MAX. DIAM. = 86.536 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 129.600 STAND. DEV. = 66.220

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	14.75	8.28	0.41	0.233	21.57	11.61

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10 -----0----0----0----0----0----0----0----0----0----0
2.50	0	0.00	[
4.00	18	2.78	[*
6.30	66	10.19	[*****
10.00	150	23.15	[************
16.00	175	27.01	[**************
25.00	155	23.92	[************
40.00	80	12.35	[******
63.00	4	0.62	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10 -----0----0----0----0----0----0----0----0----0----0
0.050	27	4.17	[**
0.100	52	8.02	[****
0.150	45	6.94	[***
0.200	32	4.94	[**
0.250	40	6.17	[***
0.300	44	6.79	[***
0.350	25	3.86	[**
0.400	46	7.10	[****
0.450	56	8.64	[****
0.500	26	4.01	[**
0.550	48	7.41	[****
0.600	46	7.10	[****
0.650	35	5.40	[***
0.700	35	5.40	[***
0.750	45	6.94	[***
0.800	29	4.48	[**
0.850	9	1.39	[*
0.900	6	0.93	[
0.950	2	0.31	[

SAMPLE ID: YY-67 7/10/77

DATA COLLECTION FOR 1171 PARTICLES

MAX. DIAM. = 66.411 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 234.200 STAND. DEV. = 59.691

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	16.00	5.93	0.50	0.275	21.12	8.09

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	4	0.34	[
6.30	52	4.44	[**
10.00	126	10.76	[*****
16.00	421	35.95	[******************
25.00	500	42.70	[*********************
40.00	65	5.55	[***
63.00	3	0.26	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	43	3.67	[**
0.100	144	12.30	[******
0.150	73	6.2[illegible]	[***
0.200	41	3.50	[**
0.250	22	1.88	[*
0.300	19	1.62	[*
0.350	19	1.62	[*
0.400	35	2.99	[*
0.450	40	3.42	[**
0.500	35	2.99	[*
0.550	54	4.61	[**
0.600	88	7.51	[****
0.650	81	6.92	[***
0.700	107	9.14	[*****
0.750	125	10.67	[*****
0.800	136	11.61	[******
0.850	76	6.49	[***
0.900	31	2.65	[*
0.950	2	0.17	[

SAMPLE ID: YY-68 7/10/77

DATA COLLECTION FOR 1054 PARTICLES

MAX. DIAM. = 72.549 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 210.800 STAND. DEV.= 81.500

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	13.98	5.51	0.49	0.253	18.63	7.66

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	11	1.04	[*
6.30	53	5.03	[***
10.00	178	16.89	[*********
16.00	480	45.54	[***********************
25.00	305	28.94	[**************
40.00	22	2.09	[*
63.00	5	0.47	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	14	1.33	[*
0.100	106	10.06	[*****
0.150	70	6.64	[***
0.200	40	3.80	[**
0.250	25	2.37	[*
0.300	25	2.37	[*
0.350	35	3.32	[**
0.400	39	3.70	[**
0.450	54	5.12	[***
0.500	24	2.28	[*
0.550	69	6.55	[***
0.600	92	8.73	[****
0.650	63	5.98	[***
0.700	107	10.15	[*****
0.750	131	12.43	[******
0.800	98	9.30	[*****
0.850	40	3.80	[**
0.900	21	1.99	[*
0.950	1	0.09	[

SAMPLE ID: YY-71 7/10/77

DATA COLLECTION FOR 838 PARTICLES

MAX. DIAM. = 108.673 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 167.600 STAND. DEV. = 62.443

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	17.44,	7.27	0.43	0.285	23.76	10.43

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	16	1.91	[*
6.30	24	2.86	[*
10.00	85	10.14	[*****
16.00	259	30.91	[***************
25.00	314	37.47	[******************
40.00	137	16.35	[********
63.00	3	0.36	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	60	7.16	[****
0.100	142	16.95	[********
0.150	53	6.32	[***
0.200	30	3.58	[**
0.250	15	1.79	[*
0.300	25	2.98	[*
0.350	19	2.27	[*
0.400	23	2.74	[*
0.450	28	3.34	[**
0.500	17	2.03	[*
0.550	51	6.09	[***
0.600	52	6.21	[***
0.650	51	6.09	[***
0.700	74	8.83	[****
0.750	78	9.31	[*****
0.800	66	7.88	[****
0.850	31	3.70	[**
0.900	22	2.63	[*
0.950	1	0.12	[

SAMPLE ID: YY-72 11/10/77

DATA COLLECTION FOR 740 PARTICLES

MAX. DIAM. = 64.399 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 148.000 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.89	6.77	0.47	0.270	20.91	8.38

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 -----0-----0-----0-----0-----0-----0-----0-----0-----0-----0 (1 2 3 4 5 6 7 8 9 10)
2.50	0	0.00	[
4.00	8	1.08	[*
6.30	42	5.68	[***
10.00	113	15.27	[********
16.00	221	29.86	[***************
25.00	284	38.38	[*******************
40.00	70	9.46	[*****
63.00	2	0.27	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 -----0-----0-----0-----0-----0-----0-----0-----0-----0-----0 (1 2 3 4 5 6 7 8 9 10)
0.050	24	3.24	[**
0.100	87	11.76	[******
0.150	61	8.24	[****
0.200	32	4.32	[**
0.250	19	2.57	[*
0.300	12	1.62	[*
0.350	19	2.57	[*
0.400	18	2.43	[*
0.450	39	5.27	[***
0.500	19	2.57	[*
0.550	42	5.68	[***
0.600	60	8.11	[****
0.650	38	5.14	[***
0.700	62	8.38	[****
0.750	87	11.76	[******
0.800	77	10.41	[*****
0.850	34	4.59	[**
0.900	9	1.22	[*
0.950	1	0.14	[

SAMPLE ID: YY-75 20/10/77

DATA COLLECTION FOR 1325 PARTICLES

MAX. DIAM. = 86.536 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 265.000 STAND. DEV. = 83.878

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.22	5.23	0.53	0.267	20.24	8.91

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10 -----0----0----0----0----0----0----0----0----0----0
2.50	0	0.00	[
4.00	6	0.45	[
6.30	43	3.25	[**
10.00	171	12.91	[******
16.00	527	39.77	[********************
25.00	531	40.08	[********************
40.00	47	3.55	[**

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10 -----0----0----0----0----0----0----0----0----0----0
0.050	39	2.94	[*
0.100	114	8.60	[****
0.150	92	6.94	[***
0.200	30	2.26	[*
0.250	27	2.04	[*
0.300	25	1.89	[*
0.350	31	2.34	[*
0.400	41	3.09	[**
0.450	52	3.92	[**
0.500	29	2.19	[*
0.550	59	4.45	[**
0.600	88	6.64	[***
0.650	80	6.04	[***
0.700	124	9.36	[*****
0.750	173	13.06	[*******
0.800	198	14.94	[*******
0.850	66	4.98	[**
0.900	51	3.85	[**
0.950	6	0.45	[

SAMPLE ID: YY-76 11/10/77

DATA COLLECTION FOR 1010 PARTICLES

MAX. DIAM. = 76.367 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 202.000 STAND. DEV. = 66.142

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.70	6.67	0.47	0.261	21.24	9.78

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	15	1.49	[*
6.30	61	6.04	[***
10.00	129	12.77	[******
16.00	350	34.65	[*****************
25.00	370	36.63	[******************
40.00	83	8.22	[****
63.00	2	0.20	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	33	3.27	[**
0.100	114	11.29	[******
0.150	61	6.04	[***
0.200	35	3.47	[**
0.250	27	2.67	[*
0.300	35	3.47	[**
0.350	37	3.66	[**
0.400	28	2.77	[*
0.450	48	4.75	[**
0.500	40	3.96	[**
0.550	54	5.35	[***
0.600	98	9.70	[*****
0.650	56	5.54	[***
0.700	90	8.91	[****
0.750	97	9.60	[*****
0.800	84	8.32	[****
0.850	52	5.15	[***
0.900	17	1.68	[*
0.950	4	0.40	[

SAMPLE ID: YY-77 7/10/77

DATA COLLECTION FOR 1225 PARTICLES

MAX. DIAM. = 98.611 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 204.167 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	16.44	6.59	0.52	0.267	21.44	9.57

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	5	0.41	[
6.30	46	3.76	[**
10.00	166	13.55	[*******
16.00	390	31.84	[****************
25.00	509	41.55	[*********************
40.00	105	8.57	[****
63.00	4	0.33	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	39	3.18	[**
0.100	124	10.12	[*****
0.150	74	6.04	[***
0.200	37	3.02	[**
0.250	16	1.31	[*
0.300	25	2.04	[*
0.350	24	1.96	[*
0.400	36	2.94	[*
0.450	44	3.59	[**
0.500	28	2.29	[*
0.550	73	5.96	[***
0.600	101	8.24	[****
0.650	66	5.39	[***
0.700	111	9.06	[*****
0.750	157	12.82	[******
0.800	152	12.41	[******
0.850	86	7.02	[****
0.900	30	2.45	[*
0.950	2	0.16	[

SAMPLE ID: YY-78 20/10/77

DATA COLLECTION FOR 978 PARTICLES

MAX. DIAM. = 68.424 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 195.600 STAND. DEV. = 9.990

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	18.13	6.85	0.53	0.278	23.38	9.66

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

```
CLASS          CLASS  0    1    2    3    4    5    6    7    8    9    10
LIMIT    NO.     %    -----0----0----0----0----0----0----0----0----0----0
  2.50     0    0.00 [
  4.00     9    0.92 [
  6.30    27    2.76 [*
 10.00    87    8.90 [****
 16.00   263   26.89 [*************
 25.00   441   45.09 [***********************
 40.00   145   14.83 [*******
 63.00     6    0.61 [
```

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

```
CLASS          CLASS  0    1    2    3    4    5    6    7    8    9    10
LIMIT    NO.     %    -----0----0----0----0----0----0----0----0----0----0
 0.050    39    3.99 [**
 0.100   101   10.33 [*****
 0.150    60    6.13 [***
 0.200    24    2.45 [*
 0.250    14    1.43 [*
 0.300    14    1.43 [*
 0.350    19    1.94 [*
 0.400    24    2.45 [*
 0.450    34    3.48 [**
 0.500    20    2.04 [*
 0.550    38    3.89 [**
 0.600    68    6.95 [***
 0.650    54    5.52 [***
 0.700    98   10.02 [*****
 0.750   112   11.45 [******
 0.800   121   12.37 [******
 0.850    92    9.41 [*****
 0.900    41    4.19 [**
 0.950     5    0.51 [
```

SAMPLE ID: YY-86 EACH 6/10/77

DATA COLLECTION FOR 1051 PARTICLES

MAX. DIAM. = 68.424 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 210.200 STAND. DEV. = 87.825

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.04	6.03	0.46	0.279	19.92	7.52

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	13	1.24	[*
6.30	60	5.71	[***
10.00	168	15.98	[********
16.00	359	34.16	[*****************
25.00	406	38.63	[*******************
40.00	43	4.09	[**
63.00	2	0.19	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	0	0.00	[
0.100	137	13.04	[*******
0.150	123	11.70	[******
0.200	47	4.47	[**
0.250	34	3.24	[**
0.300	42	4.00	[**
0.350	27	2.57	[*
0.400	31	2.95	[*
0.450	39	3.71	[**
0.500	21	2.00	[*
0.550	51	4.85	[**
0.600	60	5.71	[***
0.650	48	4.57	[**
0.700	81	7.71	[****
0.750	103	9.80	[*****
0.800	109	10.37	[*****
0.850	59	5.61	[***
0.900	30	2.85	[*
0.950	9	0.86	[

A3.34

SAMPLE ID: YY-89 7/10/77

DATA COLLECTION FOR 1094 PARTICLES

MAX. DIAM. = 79.200 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 218.800 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	SIGMA (UM)	MIN/MAX MEAN	SIGMA	MAXIMUM DIAMETER MEAN (UM)	SIGMA (UM)
	ALL TYPES	16.38	6.95	0.51	0.257	21.26	9.02

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	11	1.01	[*
6.30	50	4.57	[**
10.00	141	12.89	[******
16.00	384	35.10	[******************
25.00	369	33.73	[*****************
40.00	138	12.61	[******
63.00	1	0.09	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	29	2.65	[*
0.100	107	9.78	[*****
0.150	60	5.48	[***
0.200	34	3.11	[**
0.250	18	1.65	[*
0.300	19	1.74	[*
0.350	26	2.38	[*
0.400	27	2.47	[*
0.450	55	5.03	[***
0.500	39	3.56	[**
0.550	74	6.76	[***
0.600	90	8.23	[****
0.650	75	6.86	[***
0.700	106	9.69	[*****
0.750	137	12.52	[******
0.800	112	10.24	[*****
0.850	56	5.12	[***
0.900	24	2.19	[*
0.950	6	0.55	[

SAMPLE ID: YY-90 6/10/77

DATA COLLECTION FOR 895 PARTICLES

MAX. DIAM. = 86.400 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 179.000 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.02	7.15	0.48	0.253	20.61	11.15

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	7	0.78	[
6.30	54	6.03	[***
10.00	173	19.33	[**********
16.00	343	38.32	[*******************
25.00	217	24.25	[************
40.00	97	10.84	[*****
63.00	4	0.45	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	30	3.35	[**
0.100	72	8.04	[****
0.150	65	7.26	[****
0.200	35	3.91	[**
0.250	26	2.91	[*
0.300	38	4.25	[**
0.350	22	2.46	[*
0.400	32	3.58	[**
0.450	51	5.70	[***
0.500	22	2.46	[*
0.550	65	7.26	[****
0.600	93	10.39	[*****
0.650	49	5.47	[***
0.700	87	9.72	[*****
0.750	83	9.27	[*****
0.800	70	7.82	[****
0.850	34	3.80	[**
0.900	19	2.12	[*
0.950	1	0.11	[
1.000	1	0.11	[

SAMPLE ID: YY-92 7/10/77

DATA COLLECTION FOR 1151 PARTICLES

MAX. DIAM. = 84.523 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 230.200 STAND. DEV. = 11.367

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	13.62	6.02	0.50	0.246	18.10	8.69

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
1.60	0	0.00	[
2.50	1	0.09	[
4.00	14	1.22	[*
6.30	82	7.12	[****
10.00	240	20.85	[***********
16.00	480	41.70	[**********************
25.00	272	23.63	[************
40.00	61	5.30	[***
63.00	1	0.09	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	24	2.09	[*
0.100	99	8.60	[****
0.150	71	6.17	[***
0.200	31	2.69	[*
0.250	33	2.87	[*
0.300	34	2.95	[*
0.350	27	2.35	[*
0.400	35	3.04	[**
0.450	72	6.26	[***
0.500	27	2.35	[*
0.550	67	5.82	[***
0.600	102	8.86	[****
0.650	99	8.60	[****
0.700	132	11.47	[******
0.750	140	12.16	[******
0.800	97	8.43	[****
0.850	45	3.91	[**
0.900	15	1.30	[*
0.950	1	0.09	[

SAMPLE ID: YY-98 6/10/77

DATA COLLECTION FOR 977 PARTICLES

MAX. DIAM. = 88.548 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 195.400 STAND. DEV. = 50.143

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	14.67	5.66	0.49	0.250	19.77	8.11

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
1.60	0	0.00	[
2.50	1	0.10	[
4.00	7	0.72	[
6.30	51	5.22	[***
10.00	147	15.05	[********
16.00	398	40.74	[********************
25.00	340	34.80	[*****************
40.00	31	3.17	[**
63.00	2	0.20	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	10	1.02	[*
0.100	71	7.27	[****
0.150	85	8.70	[****
0.200	47	4.81	[**
0.250	25	2.56	[*
0.300	38	3.89	[**
0.350	34	3.48	[**
0.400	43	4.40	[**
0.450	47	4.81	[**
0.500	40	4.09	[**
0.550	52	5.32	[***
0.600	73	7.47	[****
0.650	63	6.45	[***
0.700	88	9.01	[*****
0.750	106	10.85	[*****
0.800	100	10.24	[*****
0.850	41	4.20	[**
0.900	13	1.33	[*
0.950	1	0.10	[

SAMPLE ID: YY-104 7/10/77

DATA COLLECTION FOR 961 PARTICLES

MAX. DIAM. = 152.947 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 192.200 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	16.51	9.54	0.46	0.253	23.71	18.24

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	16	1.66	[*
6.30	68	7.08	[****
10.00	157	16.34	[*********
16.00	291	30.28	[***************
25.00	304	31.63	[****************
40.00	100	10.41	[*****
63.00	21	2.19	[*
100.00	4	0.42	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	34	3.54	[**
0.100	84	8.74	[****
0.150	63	6.56	[***
0.200	40	4.16	[**
0.250	38	3.95	[**
0.300	37	3.85	[**
0.350	35	3.64	[**
0.400	36	3.75	[**
0.450	67	6.97	[***
0.500	34	3.54	[**
0.550	64	6.66	[***
0.600	78	8.12	[****
0.650	54	5.62	[***
0.700	86	8.95	[****
0.750	94	9.78	[*****
0.800	63	6.56	[***
0.850	35	3.64	[**
0.900	18	1.87	[*
0.950	1	0.10	[

SAMPLE ID: YY-105 6/10/77

DATA COLLECTION FOR 1106 PARTICLES

MAX. DIAM. = 98.611 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 221.200 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	14.15	6.40	0.44	0.262	19.90	9.94

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	12	1.08	[*
6.30	87	7.87	[****
10.00	197	17.81	[*********
16.00	423	38.25	[*******************
25.00	341	30.83	[***************
40.00	39	3.53	[**
63.00	7	0.63	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	25	2.26	[*
0.100	135	12.21	[******
0.150	101	9.13	[*****
0.200	53	4.79	[**
0.250	41	3.71	[**
0.300	50	4.52	[**
0.350	47	4.25	[**
0.400	47	4.25	[**
0.450	57	5.15	[***
0.500	30	2.71	[*
0.550	56	5.06	[***
0.600	88	7.96	[****
0.650	57	5.15	[***
0.700	83	7.50	[****
0.750	83	7.50	[****
0.800	96	8.68	[****
0.850	37	3.35	[**
0.900	18	1.63	[*
0.950	2	0.18	[

SAMPLE ID: YY-106 6/10/77

DATA COLLECTION FOR 894 PARTICLES

MAX. DIAM. = 76.474 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 178.800 STAND. DEV. = 82.776

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	13.51	5.30	0.46	0.254	18.19	7.29

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
1.60	0	0.00	[
2.50	1	0.11	[
4.00	18	2.01	[*
6.30	60	6.71	[***
10.00	165	18.46	[*********
16.00	364	40.72	[********************
25.00	268	29.98	[***************
40.00	18	2.01	[*

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	14	1.57	[*
0.100	102	11.41	[******
0.150	71	7.94	[****
0.200	49	5.48	[***
0.250	19	2.13	[*
0.300	30	3.36	[**
0.350	26	2.91	[*
0.400	28	3.13	[**
0.450	40	4.47	[**
0.500	30	3.36	[**
0.550	70	7.83	[****
0.600	87	9.73	[*****
0.650	58	6.49	[***
0.700	78	8.72	[****
0.750	83	9.28	[*****
0.800	74	8.28	[****
0.850	24	2.68	[*
0.900	11	1.23	[*

SAMPLE ID: YY-108 6/10/77

DATA COLLECTION FOR 784 PARTICLES.

MAX. DIAM. = 86.550 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 156.800 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	13.60	5.70	0.46	0.257	18.51	8.57

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	10	1.28	[*
6.30	50	6.38	[***
10.00	170	21.68	[***********
16.00	301	38.39	[********************
25.00	229	29.21	[***************
40.00	23	2.93	[*
63.00	1	0.13	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	20	2.55	[*
0.100	76	9.69	[*****
0.150	74	9.44	[*****
0.200	34	4.34	[**
0.250	25	3.19	[**
0.300	23	2.93	[*
0.350	30	3.83	[**
0.400	30	3.83	[**
0.450	36	4.59	[**
0.500	23	2.93	[*
0.550	59	7.53	[****
0.600	63	8.04	[****
0.650	56	7.14	[****
0.700	61	7.78	[****
0.750	68	8.67	[****
0.800	69	8.80	[****
0.850	27	3.44	[**
0.900	9	1.15	[*
0.950	1	0.13	[

SAMPLE ID: YY-113 7/10/77

DATA COLLECTION FOR 882 PARTICLES

MAX. DIAM. = 91.641 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 176.400 STAND. DEV. = 88.988

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	18.32	8.24	0.48	0.286	24.33	11.50

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

```
CLASS          CLASS  0    1    2    3    4    5    6    7    8    9    10
LIMIT     NO.    %    -----0----0----0----0----0----0----0----0----0----0
   2.50     0   0.00 [
   4.00     6   0.68 [
   6.30    44   4.99 [**
  10.00   103  11.68 [******
  16.00   224  25.40 [*************
  25.00   312  35.37 [******************
  40.00   184  20.86 [**********
  63.00     9   1.02 [*
```

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

```
CLASS          CLASS  0    1    2    3    4    5    6    7    8    9    10
LIMIT     NO.    %    -----0----0----0----0----0----0----0----0----0----0
  0.050    46   5.22 [***
  0.100   118  13.38 [*******
  0.150    63   7.14 [****
  0.200    18   2.04 [*
  0.250    17   1.93 [*
  0.300    19   2.15 [*
  0.350    21   2.38 [*
  0.400    16   1.81 [*
  0.450    42   4.76 [**
  0.500    15   1.70 [*
  0.550    51   5.78 [***
  0.600    60   6.80 [***
  0.650    40   4.54 [**
  0.700    72   8.16 [****
  0.750    85   9.64 [*****
  0.800   100  11.34 [******
  0.850    56   6.35 [***
  0.900    43   4.88 [**
```

SAMPLE ID: YY-122 7/10/77

DATA COLLECTION FOR 1263 PARTICLES

MAX. DIAM. = 112.698 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 252.600 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	14.45	8.48	0.39	0.232	21.99	12.85

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

```
CLASS            CLASS  0    1    2    3    4    5    6    7    8    9    10
LIMIT     NO.      %    -----0----0----0----0----0----0----0----0----0----0
  2.50      0    0.00 [
  4.00     28    2.22 [*
  6.30    133   10.53 [*****
 10.00    309   24.47 [************
 16.00    382   30.25 [***************
 25.00    250   19.79 [**********
 40.00    145   11.48 [******
 63.00     16    1.27 [*
```

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

```
CLASS            CLASS  0    1    2    3    4    5    6    7    8    9    10
LIMIT     NO.      %    -----0----0----0----0----0----0----0----0----0----0
 0.050     36    2.85 [*
 0.100    101    8.00 [****
 0.150    106    8.39 [****
 0.200     91    7.21 [****
 0.250     88    6.97 [***
 0.300    109    8.63 [****
 0.350     68    5.38 [***
 0.400     90    7.13 [****
 0.450     93    7.36 [****
 0.500     44    3.48 [**
 0.550     67    5.30 [***
 0.600     78    6.18 [***
 0.650     49    3.88 [**
 0.700     71    5.62 [***
 0.750     79    6.25 [***
 0.800     52    4.12 [**
 0.850     25    1.98 [*
 0.900     15    1.19 [*
 0.950      1    0.08 [
```

SAMPLE ID: YY-123 7/10/77

DATA COLLECTION FOR 1409 PARTICLES

MAX. DIAM. = 78.486 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 281.800 STAND. DEV.= 58.658

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	11.52	4.44	0.47	0.240	15.55	6.27

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
1.60	0	0.00	[
2.50	1	0.07	[
4.00	17	1.21	[*
6.30	140	9.94	[*****
10.00	406	28.81	[**************
16.00	640	45.42	[***********************
25.00	199	14.12	[*******
40.00	5	0.35	[
63.00	1	0.07	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	17	1.21	[*
0.100	111	7.88	[****
0.150	116	8.23	[****
0.200	67	4.76	[**
0.250	49	3.48	[**
0.300	40	2.84	[*
0.350	38	2.70	[*
0.400	63	4.47	[**
0.450	74	5.25	[***
0.500	50	3.55	[**
0.550	104	7.38	[****
0.600	164	11.64	[******
0.650	87	6.17	[***
0.700	143	10.15	[*****
0.750	146	10.36	[*****
0.800	85	6.03	[***
0.850	35	2.48	[*
0.900	17	1.21	[*
0.950	3	0.21	[

A3.45

SAMPLE ID: YY-124 6/10/77

DATA COLLECTION FOR 954 PARTICLES

MAX. DIAM. = 66.411 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 190.800 STAND. DEV. = 0.000

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	16.21	6.37	0.53	0.257	20.81	7.90

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	9	0.94	[
6.30	49	5.14	[***
10.00	129	13.52	[*******
16.00	260	27.25	[**************
25.00	441	46.23	[***********************
40.00	65	6.81	[***
63.00	1	0.10	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	18	1.89	[*
0.100	83	8.70	[****
0.150	54	5.66	[***
0.200	22	2.31	[*
0.250	25	2.62	[*
0.300	22	2.31	[*
0.350	17	1.78	[*
0.400	29	3.04	[**
0.450	40	4.19	[**
0.500	36	3.77	[**
0.550	48	5.03	[***
0.600	69	7.23	[****
0.650	48	5.03	[***
0.700	102	10.69	[*****
0.750	137	14.36	[*******
0.800	112	11.74	[******
0.850	58	6.08	[***
0.900	29	3.04	[**
0.950	5	0.52	[

SAMPLE ID: YY-125 7/10/77

DATA COLLECTION FOR 879 PARTICLES

MAX. DIAM. = 72.000 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 175.800 STAND. DEV. = 81.445

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	16.94	8.70	0.47	0.261	22.97	10.68

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	15	1.71	[*
6.30	51	5.80	[***
10.00	140	15.93	[********
16.00	259	29.47	[***************
25.00	257	29.24	[***************
40.00	150	17.06	[*********
63.00	7	0.80	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	33	3.75	[**
0.100	76	8.65	[****
0.150	58	6.60	[***
0.200	35	3.98	[**
0.250	28	3.19	[**
0.300	37	4.21	[**
0.350	35	3.98	[**
0.400	53	6.03	[***
0.450	56	6.37	[***
0.500	19	2.16	[*
0.550	55	6.26	[***
0.600	72	8.19	[****
0.650	44	5.01	[***
0.700	61	6.94	[***
0.750	65	7.39	[****
0.800	73	8.30	[****
0.850	45	5.12	[***
0.900	31	3.53	[**
0.950	3	0.34	[

SAMPLE ID: YY-126 6/10/77

DATA COLLECTION FOR 883 PARTICLES

MAX. DIAM. = 80.499 UM MIN. DIAM. = 0.900 UM

PARTICLES/FRAME: MEAN= 176.600 STAND. DEV. = 83.120

PART TYPE	CHEMICAL NAME	AVERAGE DIAMETER MEAN (UM)	AVERAGE DIAMETER SIGMA (UM)	MIN/MAX MEAN	MIN/MAX SIGMA	MAXIMUM DIAMETER MEAN (UM)	MAXIMUM DIAMETER SIGMA (UM)
	ALL TYPES	15.27	7.26	0.41	0.259	21.77	9.50

FOR ALL TYPES

AVERAGE DIAMETER (UM) DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
2.50	0	0.00	[
4.00	12	1.36	[*
6.30	55	6.23	[***
10.00	152	17.21	[*********
16.00	317	35.90	[******************
25.00	240	27.18	[**************
40.00	105	11.89	[******
63.00	2	0.23	[

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS LIMIT	NO.	CLASS %	0 1 2 3 4 5 6 7 8 9 10
0.050	39	4.42	[**
0.100	101	11.44	[******
0.150	89	10.08	[*****
0.200	39	4.42	[**
0.250	44	4.98	[**
0.300	52	5.89	[***
0.350	36	4.08	[**
0.400	48	5.44	[***
0.450	49	5.55	[***
0.500	25	2.83	[*
0.550	37	4.19	[**
0.600	53	6.00	[***
0.650	43	4.87	[**
0.700	67	7.59	[****
0.750	63	7.13	[****
0.800	60	6.80	[***
0.850	28	3.17	[**
0.900	9	1.02	[*
0.950	1	0.11	[

Appendix 4. The Results of Residual Mg Content, Nodule Count, Nodularity and Nodularization Index.

Sample No.	FeSiMg/$BaCl_2$ (gm)	Temp. (C)	Holding Time (min)	Nodule Count (No./mm^2)	Nodularity %	Nodularization Index relative(normalized)	Residual Mg%
A10 (F*)	4/4	1500	0	400	100	27500 (69)	0.086
A11 (F*)	4/4	1500	5	379	95	24226 (61)	0.038
A12 (F*)	4/4	1500	10	292	60	9721 (24)	0.003
A13 (F*)	4/4	1500	15	0	0	0 (0)	0.001
A20 (F*)	4/4	1470	0	450	85	26168 (66)	0.102
A21 (F*)	4/4	1470	5	311	75	16461 (41)	0.026
A22 (F*)	4/4	1470	10	280	70	13244 (33)	0.002
A24 (F*)	4/4	1470	20	334	50	9342 (23)	0.002
A30 (F*)	4/4	1400	0	637	90	39870 (100)	0.059
A31 (F*)	4/4	1400	5	361	60	14866 (37)	0.003
A32 (F*)	4/4	1400	10	305	70	13454 (34)	0.002
A33 (F*)	4/4	1400	15	253	75	12589 (32)	0.011

Appendix 4. The Results of Residual Mg Content, Nodule Count, Nodularity and Nodularization Index.
(Legend: F: Ford material; H: Hanna material; B: Bendix material
*: fast cool; **: slow cool)

Sample No.	FeSiMg /$BaCl_2$ (gm)	Additions (gm)	Temp. (C)	Holding Time (min)	Nodule Count (No./mm^2)	Nodularity %	Nodularization Index relative (normalized)	Residual Mg%
A34 (F*)	4/4	-	1400	20	351	75	18368 (46)	0.003
A40 (F*)	4/4	-	1350	0	504	85	30578 (77)	0.140
A41 (F*)	4/4	-	1350	5	499	70	21232 (53)	0.013
A43 (F*)	4/4	-	1350	15	391	75	17595 (44)	0.007
A45 (F*)	4/4	-	1350	30	240	70	10798 (27)	0.012
Y0 (F*)	4/4	0.4 MgO	1370	20	-	-	-	0.005
M6 (F*)	4/4	0.4 MgO	1450	20	-	-	-	0.009
F10 (F*)	4/4	0.4 MgO	1500	0	-	-	-	0.043
F11 (F*)	0/0	-	1500	5	-	-	-	0.040
F12 (F*)	0/0	-	1500	7	-	-	-	0.023
F13 (F*)	0/0	-	1500	15	-	-	-	0.009
AM11(F*)	4/4	0.4 MgO	1500	5	-	-	-	0.020
AM12(F*)	4/4	0.4 MgO	1500	10	-	-	-	0.001
HM14(F*)	4/4	0.4 MgO	1500	20	-	-	-	0.002
X1 (F*)	4/4	0.4 MgO	1550	20	-	-	-	0.007

Sample No.	$FeSiMg/BaCl_2$ (gm)	Additions (gm)	Ford Inocu. (gm)	Temp. (C)	Holding Time (min)	Residual Mg%
A2M4 (F*)	4/4	0.2 MgO	-	1470	20	0.007
A1M4 (F*)	4/4	0.2 MgO	-	1500	20	0.002
A1M4-2(F*)	4/4	0.4 MgO	-	1500	20	0.026
A1M4-c(F*)	4/4	0.4 MgO	1	1500	20	0.008
W2 (F*)	4/2	0.2 MgO	-	1500	20	0.005
W1 (F*)	4/1	0.1 MgO	-	1500	20	0.025
F101 (F*)	4/4	0.4 MgO	-	1500	0	0.111
F14 (F*)	0/4	-	-	1500	20	0.010
P1 (F*)	4/3	0.3 MgO	-	(just melt)	0	0.032
P2 (F*)	0/0	-	-	1450	20	0.010
P3 (F*)	0/4	-	-	1450	20	0.006
P4 (F*)	0/4	0.4 MgO	-	1450	20	0.005
S10 (F*)	4/4	0.4 MgO-1.0 CaSi	-	1500	0	0.050
S11 (F*)	4/4	"	-	"	5	0.014
S13 (F*)	4/4	"	-	"	15	0.002
S14 (F*)	4/4	"	-	"	20	0.004

Sample No.	FeSiMg/$BaCl_2$ (gm)	Additions (gm)	Temp. (C)	Holding Time (min)	Residual Mg%
A1M4-C1 (F*)	4/4	0.4 MgO-0.5 CaSi	1500	20	0.001
MM1 (F*)	4/4	0.2 MgO-0.2 $MgCl_2$	1500	20	0.010
MM2 (F*)	4/4	0.2 MgO-0.4 $MgCl_2$	1500	20	0.007
MM3 (F*)	4/4	0.4 MgO-0.2 $MgCl_2$	1500	20	0.007
AAM14 (F*)	4/4	0.2 MgO-0.2 Al_2O_3	1500	20	0.001
AMY13 (F*)	4/4	0.3 MgO-0.1 Ce_2O_3	1500	15	0.003
C1M3 (F*)	4/0 (4 gm $CaCl_2$)	0.4 MgO	1500	15	0.004
C3M4 (F*)	4/0 (4 gm $CaCl_2$)	0.4 MgO	1400	20	0.002
NM10 (F*)	4/0 (4 gm NaCl)	0.4 MgO	1400	2	0.051
Y1 (F*)	4/4	0.4 Al_2O_3	1500	20	0.004
Y12 (F*)	4/4	0.4 Al_2O_3	1370	20	0.015
Y16 (F*)	4/4	0.2 Al_2O_3	1500	20	0.005
AA34 (F*)	4/4	0.4 Al_2O_3	1400	20	0.009
CA23 (F*)	4/0 (4 gm $CaCl_2$)	0.4 Al_2O_3	1450	15	0.001

Sample No.	FeSiMg /$BaCl_2$ (gm)	Slag/gm	Additions (gm)	Temp. (C)	Holding Time (min)	Residual Mg%
Y21 (F*)	4/4	-	0.4 CaO	1370	20	< 0.001
Y31 (F*)	4/4	-	0.4 SiO_2	1370	20	< 0.001
Y5 (F*)	4/4	-	0.4 Ce_2O_3	1370	20	0.004
M1 (F*)	4/4	-	0.4 $MgCl_2$	1500	20	0.014
M2 (F*)	4/4	-	0.8 $MgCl_2$	1500	20	0.008
M3 (F*)	4/4	-	-	1450	20	0.004
M4 (F*)	4/4	-	0.4 $MgCl_2$	1450	20	0.005
M5 (F*)	4/4	-	0.8 $MgCl_2$	1450	20	0.008
M7 (F*)	4/4	-	0.8 $MgCl_2$	1450	0	0.034
M8 (F*)	2/4	-	0.8 $MgCl_2$	1450	20	0.005
M10 (F*)	0/4	-	0.8 $MgCl_2$	1450	0	0.007
YY5 (F*)	4/4	I/4	-	1500	20	0.012
YY10 (F*)	4/4	I/4	-	1500	20	0.023
YY21 (F*)	2/4	I/2	-	1500	20	0.012
YY44 (F**)	4/4	I/4	-	1350	20	0.055

Sample No.	FeSiMg /$BaCl_2$ (gm)	Inoculant (gm)	Slag /gm	Temp. (C)	Holding Time (min)	Nodule Count (No./mm^2)	Nodularity %	Nodularization Index relative (normalized)	Residual Mg%
YY79 (F**)	4/4	1	I/4	1350	20	-	-	-	0.055
YY54 (F**)	4/4	-	I/4	1550	20	-	-	-	0.015
YY42 (F**)	4/4	-	I/4	1500	20	254	60	10292 (26)	0.035
YY45 (F**)	4/4	-	I/4	1500	20	255	70	12337 (31)	0.039
YY3 (F*)	4/4	-	I/4	1500	20	333	100	22378 (56)	0.040
YY11 (F*)	4/4	1	I/4	1500	20	-	-	-	0.018
YY61 (F**)	4/4	1	I/4	1550	20	-	-	-	0.016
YY1 (F*)	0/0	-	I/4	1500	20	-	-	-	0.008
YY6 (F*)	4/0 (4 gm $CaCl_2$)	-	I/4	1500	20	-	-	-	0.007
YY26 (F*)	4/4 (1 gm $CaCl_2$)	-	I/3	1500	20	-	-	-	0.025
YY8 (F*)	4/4	-	I-1/4	1500	20	-	-	-	0.009
YY9 (F*)	4/4	-	I-1/4	1500	20	-	-	-	0.020
YY41 (F**)	4/4	-	I-1/4	1500	20	328	75	14770 (37)	0.035

Sample No.	FeSiMg /$BaCl_2$ (gm)	Inoculant (gm)	Slag /gm	Temp. (C)	Holding Time (min)	Nodule Count (No./mm^2)	Nodularity %	Nodularization Index relative(normalized)	Residual Mg%
YY43 (F**)	4/4	-	I-2/4	1500	20	345	80	16984(43)	0.035
YY46 (F**)	4/4	-	I-2/4	1500	20	211	80	11221(28)	0.042
YY55 (F**)	4/4	-	I-2/4	1500	20	264	65	10391(26)	0.060
YY12 (F**)	4/4	-	I-2/4	1500	20	-	-	-	0.018
YY7 (F**)	4/4	-	I-2/4	1500	20	-	-	-	0.015
YY29 (F*)	4/4	-	I-3/4	1500	20	-	-	-	0.021
YY2 (F*)	0/0	-	II/4	1500	10	-	-	-	0.007
YY4 (F*)	4/4	-	II/4	1500	20	-	-	-	0.008
YY13 (F*)	4/4	-	II/4	1500	20	-	-	-	0.006
YY20 (F*)	4/4	-	II/4	1500	20	-	-	-	0.028
YY48 (F**)	4/4	-	II/4	1500	20	-	-	-	0.082
YY56 (F**)	4/4	-	II/4	1500	20	-	-	-	0.009
YY60 (F**)	4/4	-	II/4	1550	20	-	-	-	0.038
YY62 (F**)	4/4	1	II-2/4	1550	20	-	-	-	0.040

Sample No.	FeSiMg /$BaCl_2$ (gm)	Inoculant (gm)	Slag /gm	Temp. (C)	Holding Time (min)	Nodule Count (No./mm^2)	Nodularity %	Nodularization Index relative (normalized)	Residual Mg%
YY25 (F*)	2/4	-	II/1 (1 gm $BaCl_2$)	1500	20	-	-	-	0.019
YY64 (F**)	4/4	-	II/3 (1 gm $BaCl_2$)	1550	20	-	-	-	0.040
YY49 (F**)	4/4	-	II-2/4	1500	20	-	-	-	0.006
YY57 (F**)	4/4	-	II-2/4	1550	20	-	-	-	0.042
YY53 (F**)	4/4	-	-	1550	20	-	-	-	0.004
YY65 (F**)	4/4	-	II-2/4	1500	20	-	-	-	0.045
YY66 (F**)	4/4	-	II-2/4	1500	20	-	-	-	0.030
YY67 (F**)	4/4	-	II-3/4	1500	20	478	90	28570 (72)	0.071
YY68 (F**)	4/4	1	II-3/4	1500	20	430	85	25379 (64)	0.069
YY69 (F**)	2/4	1	II-3/4	1500	20	-	-	-	0.040
YY70 (F**)	2/2	1	II-3/4	1500	20	-	-	-	0.003
YY71 (F**)	4/4	1	II-3/4	1550	20	342	70	17363 (44)	0.100
YY72 (F**)	4/4	1	II-3/4	1500	30	302	80	16740 (42)	0.053
YY73 (F**)	4/4	1	II-3/2	1500	20	-	-	-	0.015

Sample No.	FeSiMg /$BaCl_2$ (gm)	Inoculant (gm)	Slag /gm	Temp. (C)	Holding Time (min)	Nodule Count (No./mm^2)	Nodularity %	Nodularization Index relative (normalized)	Residual Mg%
YY74 (F**)	0/0	-	II-3/4	1500	20	-	-	-	0.001
YY75 (F**)	4/4	1	II-3/4	1500	0	541	95	34500(87)	0.100
YY76 (F**)	4/4	1	II-3/4	1500	5	412	80	22516(56)	0.085
YY77 (F**)	4/4	1	II-3/4	1500	15	417	95	26484(66)	0.082
YY78 (F**)	4/4	1	II-3/4	1350	20	399	95	25700(64)	0.075
YY82 (H**)	4/4	1	II-3/4	1500	20	-	-	-	0.040
YY85 (B**)	8/4	2	II-3/4	1500	20	-	-	-	0.005
YY86 (H**)	4/4	1	II-3/4	1500	20	429	80	22450(56)	0.066
YY89 (H**)	4/4	1	II-3/4	1500	20	447	90	27786(70)	0.092
YY80 (B**)	4/4	1	II-3/4	1500	20	-	-	-	0.001
YY90 (F**)	4/4	1	II-3/4	1500	20	365	85	20466(51)	0.198
YY92 (F*)	4/4	1	II-3/4	1500	20	470	90	28501(71)	0.220
YY114(H**)	4/4	1	II-3/4	1500	20	-	-	-	<0.001
YY122(F**)	4/4	-	II-3/4	1500	20	516	60	17854(45)	0.005

Note: Slag II-3 used in YY114 and YY122 is "wet".

Sample No.	FeSiMg /$BaCl_2$ (gm)	Inoculant (gm)	Slag/gm	Temp. (C)	Holding Time (min)	Nodule Count (No./mm^2)	Nodularity %	Nodularization Index relative (normalized)	Residual Mg%
YY93 (B**)	4/4	1	-	1500	0	-	-	-	0.021
YY94 (H**)	4/4	1	-	1500	0	-	-	-	0.075
YY95 (H**)	4/4	1	-	1500	20	-	-	-	0.008
YY98 (F**)	4/4	1	II-4/4	1500	20	399	85	21933(55)	0.055
YY100(F**)	4/4	1	II-5/4	1500	20	-	-	-	0.049
YY102(F**)	4/4	1	II-6/4	1500	20	-	-	-	0.026
YY103(F**)	4/4 (1 gm $MgCl_2$)	1	II-6/4	1500	20	-	-	-	0.006
YY96 (F**)	4/4	1	Ex-II/4	1500	20	-	-	-	0.058
YY104(F**)	4/4	1	II-7/4	1550	20	392	80	20110(50)	0.082
YY105(F**)	4/4	1	II-7/4	1500	20	451	75	21202(53)	0.024
YY124(F**)	4/4	-	II-7/4	1500	20	389	95	24787(62)	0.033
YY106(F**)	4/4	1	II-8/4	1500	20	365	80	19798(50)	0.045
YY125(F**)	4/4	0	II-8/4	1500	30	359	80	18338(46)	0.042
YY107(F**)	4/4	1	II-9/4	1500	20	-	-	-	0.017

Sample No.	FeSiMg /$BaCl_2$ (gm)	Inoculant (gm)	Slag/gm	Temp. (C)	Holding Time (min)	Nodule Count (No./mm^2)	Nodularity %	Nodularization Index relative (normalized)	Residual Mg%
YY108 (F**)	4/4	1	II-10/4	1500	20	320	80	16858 (42)	0.038
YY126 (F**)	4/4	-	II-10/4	1500	20	360	65	14717 (37)	0.028
YY110 (F**)	4/4	1	II-13/4	1500	20	-	-	-	0.005
YY111 (F**)	4/4	1	II-14/4	1500	20	-	-	-	0.013
YY112 (F**)	4/4	1	II-15/4	1500	20	-	-	-	0.011
YY113 (F**)	4/4	1	II-16/4	1500	20	360	85	20696 (52)	0.055
YY123 (F**)	4/4	-	II-16/4	1500	20	575	80	31987 (80)	0.036
YY115 (F**)	4/4	1	II-17/4	1500	20	-	-	-	<0.001
YY116 (F**)	4/4	1	II-18/4	1500	20	-	-	-	<0.001
YY118 (F**)	0/0	-	II-18/4	1500	20	-	-	-	0.001
YY117 (F**)	4/0 (4 gm $CaCl_2$)	-	II-19/4	1500	20	-	-	-	0.004
YY127 (F**)	4/4	-	II-20/4	1500	20	-	-	-	0.013
YY128 (F**)	4/4	-	II-20/4	1500	20	-	-	-	0.012

Sample No.	FeSiMg/$BaCl_2$ (gm)	Inoculant (gm)	Slags/gm	Temp. (C)	Holding Time (min)	Residual Mg%
YY97 (F**)	4/4	1	I/2 & II-3/2	1500	20	0.013
YY99 (F**)	4/4	1	II-3/2 & II-4/2	1500	20	0.040
YY101 (F**)	4/4	1	II-3/2 & II-5/2	1500	20	0.081
YY14 (F*)	4/4	-	III/4	1500	20	0.023
YY15 (F*)	4/4	1	III/4	1500	20	0.013
YY22 (F*)	4/4	-	III/2	1500	20	0.005
YY23 (F*)	2/4	-	III/2	1500	20	0.004
YY58 (F**)	4/4	-	III/4	1550	20	0.038
YY63 (F**)	4/4	-	III/3 & 1 gm $BaCl_2$	1550	20	0.025
YY16 (F*)	4/4	-	III-1/4	1500	20	0.012
YY17 (F*)	4/4	1	III-1/4	1500	20	0.025
YY39 (F**)	4/4	-	III-1/4	1500	20	0.008
YY52 (F**)	4/4	-	III-1/4	1500	20	0.025

Sample No.	FeSiMg/$BaCl_2$ (gm)	Inoculant (gm)	Slags/gm	Temp. (C)	Holding Time (min)	Residual Mg%
YY24 (F*)	2/4	-	III/1 & III-1/1	1500	20	0.011
YY27 (F*)	2/4	1	"	1500	20	0.012
YY28 (F*)	2/4	1	"	1500	20	0.002
YY33 (F*)	4/4	-	III/2 & III-1/2	1500	20	0.007
YY35 (F*)	4/4	1	"	1500	20	0.019
YY38 (F**)	4/4	-	"	1500	20	0.041
YY18 (F*)	4/4	-	IV/4	1500	20	0.006
YY19 (F*)	4/4	-	V/4	1500	20	0.013
YY40 (F**)	4/4	-	V/4	1500	20	0.031
YY119 (F**)	4/0	-	4 gm $CaCl_2$ & 4 gm calsibar	1500	20	0.003
YY120 (F**)	2/0	-	4 gm $CaCl_2$ & 2 gm calsibar	1500	20	0.003
YY121 (F**)	0/0	-	4 gm $CaCl_2$ & 4 gm $CaSi_2$	1500	20	0.019
YY129 (F**)	4/4	-	4 gm SiC	1500	20	0.004

VITA AUCTORIS

1950	Born in Hong Kong.
1956	Educated at Chi-Yun Elementary School, Taipei, Taiwan, R. O. C.
1968	Graduated from Provincial Fu-Hsing High School, Taipei, Taiwan, R. O. C.
1973	Graduated with degree of Hons. B. Sc., National Cheng-Kung University, Tainan, Taiwan, R. O. C.
1973	Military Service in Army, Taiwan, R. O. C.
1975	Registered as full-time graduate student in the Master programme of the Department of Engineering Materials at the University of Windsor, Windsor, Ontario, Canada.